Technical Report 1211

Simulator Sickness During Emergency Procedures Training in a Helicopter Simulator: Age, Flight Experience, and Amount Learned

David M. Johnson
U.S. Army Research Institute

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United States Army Research Institute for the Behavioral and Social Sciences

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14. ABSTRACT *(Maximum 200 words)*:

This research measured simulator sickness both before and after exposure to a helicopter simulator that was being used for emergency procedures training. Research issues were the incidence and magnitude of simulator sickness, aftereffects, susceptibility, and the effect of simulator sickness on training effectiveness. A total of 474 AH-64A (Apache) Army aviators participated in this research. The Simulator Sickness Questionnaire (SSQ) was administered prior to simulator exposure, immediately after simulator exposure, and twelve hours later. The incidence rate following simulator exposure was 68 percent. The SSQ Total Severity score was significantly larger immediately after exposure than it was prior to simulator exposure or twelve hours later. Age was significantly and positively correlated with SSQ score, after the effect of total flight hours was held constant. Flight hours did not correlate with SSQ score, after the effect of age was held constant. These results were consistent with postural instability theory. Both prior history of motion sickness and prior history of simulator sickness were significantly and positively correlated with SSQ score. The strongest susceptibility factor noted in this research was prior history of simulator sickness. SSQ score was not correlated with training effectiveness, as measured by a short behavioral test.

15. SUBJECT TERMS

Simulator Sickness Motion Sickness Flight Simulation Flight Training Helicopter Training
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David M. Johnson
U.S. Army Research Institute

Rotary-Wing Aviation Research Unit
William R. Howse, Chief

U.S. Army Research Institute for the Behavioral and Social Sciences
2511 Jefferson Davis Highway, Arlington, Virginia 22202-3926

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SIMULATOR SICKNESS DURING EMERGENCY PROCEDURES TRAINING IN A HELICOPTER SIMULATOR: AGE, FLIGHT EXPERIENCE, AND AMOUNT LEARNED

EXECUTIVE SUMMARY

Research Requirement:

One purpose of this research was to review the literature pertaining to simulator sickness. Special emphasis was given to sickness issues as they related to simulator-based helicopter training. A second purpose of this research was to measure simulator sickness both before and after exposure to a helicopter simulator that was being used for emergency procedures training. The research issues were the incidence and magnitude of simulator sickness, aftereffects, susceptibility, and the effect of simulator sickness on training effectiveness.

Procedure:

A library search was undertaken to uncover the relevant literature. Helicopter studies were emphasized. A total of 474 Army aviators participated in this research. All participants were enrolled in the AH-64A Aircraft Qualification Course at Fort Rucker, AL. Participants were administered the Simulator Sickness Questionnaire prior to simulator exposure, immediately after simulator exposure, and twelve hours later. In addition, participants were questioned as to their age, total flight hours, prior history of motion sickness, and prior history of simulator sickness. A no-notice, behavioral test that sampled prior instruction was given during the training session. Participants were also questioned about potential aftereffects twelve hours after finishing the simulator-based training.

Findings:

Literature findings were reviewed in the introductory sections of the report. Examples of empirical findings from this research follow. The simulator sickness incidence rate following simulator exposure was 68.1 percent. The Total Severity score from the Simulator Sickness Questionnaire was significantly larger immediately after simulator exposure than it was prior to simulator exposure or twelve hours later. Twenty-two participants (4.6%) experienced such a high level of discomfort that simulator training was stopped for an unscheduled break. No participants (0%) reported having been involved in an automobile or motorcycle accident in the twelve hours immediately following simulator-based training. Aviator age was significantly and positively correlated with Total Severity score, after the effect of total flight hours was held constant. Flight hours did not correlate with Total Severity score, after the effect of age was held constant. These results were consistent with postural instability theory. Both prior history of motion sickness and prior history of simulator sickness were significantly and positively correlated with Total Severity score. The strongest susceptibility factor noted in this research was prior history of simulator sickness. Performance on the in-simulator behavioral test was not related to Total Severity score. That is, this research found no relationship between amount of discomfort and amount learned during the emergency procedures training. This last finding could have been due to psychometric weaknesses exhibited by the test itself.

Utilization and Dissemination of Findings:

Early results of this research were briefed to the 1st Battalion/14th Aviation Regiment as well as to the Directorate of Simulation (DOS) at the U.S. Army Aviation Warfighting Center. Final results will be made available to DOS as well as to the U.S. Army Aeromedical Research Laboratory. These results are part of the research substrate that supports the enhanced simulator-based flight training program called Flight School XXI.

SIMULATOR SICKNESS DURING EMERGENCY PROCEDURES TRAINING IN A HELICOPTER SIMULATOR: AGE, FLIGHT EXPERIENCE, AND AMOUNT LEARNED

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Introduction

There are several advantages of simulation for aviation training (e.g., Kennedy, Berbaum, Lilienthal, Dunlap, Mulligan, & Funaro, 1987; Kennedy, Lilienthal, Berbaum, Baltzley, & McCauley, 1989). Emergency procedures can be trained and practiced in safety. Foul weather does not delay or halt simulator-based training. Further, there are special training options available with simulation that do not exist in live aircraft training. For example, the freeze command can be used to stop the aircraft to provide instruction or prevent a crash. Preprogrammed reset locations can be used to reposition the aircraft for the next task, or a repeat of the prior task, without having to expend valuable training time flying back to an optimal starting point. Simulator-based training can occur in real time, slow motion, or faster-than-real time (Crane & Guckenberger, 2000). Automatic feedback features can be preprogrammed and simulator flights can be recorded for replay and later examination. Not least among the advantages of simulator-based training is cost savings.

Simulator Cost Savings

Simulators have been shown to provide effective training at relatively low cost since at least the 1970s (e.g., Orlansky & String, 1977). Simulators are 10 to 30 times more available for training than aircraft. They save on fuel. In some cases the cost of the simulator can be regained in savings within the first 18 months. The relative cost per hr of training in a simulator has been estimated as 5% to 20% that of the actual aircraft (Pausch, Crea, & Conway, 1992). According to U.S. Air Force (USAF) calculations (Moorman, 2002), an hr of training in a C-5 aircraft costs taxpayers $10,000 while an hr in a USAF C-5 simulator is $500, a ratio of 20:1 in favor of the simulator. *Jane's Defence Weekly* (2002) reported that the hourly cost of a Boeing 747 aircraft versus a Level D flight simulator of that aircraft was about 40:1. *Jane's* went on to report that for military fighter or attack aircraft the relative aircraft to simulator ratios were in the region of 10 or 20 to 1. The U.S. Navy reported that the relative cost ratios for training in a F/A-18 are 18:1 and for training in a SH-60 Blackhawk helicopter are 15:1 (*Jane's Defence Weekly*). Similar figures for training in an M-1 tank versus an M-1 tank simulator, not counting ammunition, were reported as 33:1 (*Jane's Defence Weekly*). Lampton, Kraemer, Kolasinski, and Knerr (1995) reported that the cost per mile of driving an M-1 tank was $92, while it was $6 per mile for an M-1 tank driver simulator, a cost ratio of about 15:1.

The U.S. Army Aviation Center (USAAVNC) at Fort Rucker trains more than 1,200 aviators every year (Spires, 2003, March). Official documents listed the cost to train a single aviator at $1.1 million (Czarnecki, 2004; Department of the Army, 1994, November). The estimated cost per hr of flight training in a live aircraft can vary widely depending upon how much of the training infrastructure and associated materiel costs are included. Spires estimated that the hourly cost of operating the TH-67 training helicopter was $125, while the UH-60 Blackhawk was $2,000 per hr. USAAVNC (2003) calculated costs based on a variety of factors including instructor labor, maintenance labor and parts, installation overhead, fuel, oil, and

lubricants. The costs per flight hr for training varied from a low of $781 for the TH-67 to a high of $6,095 for the AH-64D Apache.

Recently the Army Aviation Center changed its name to U.S. Army Aviation Warfighting Center (USAAWC). In fiscal year 2006, USAAWC implemented its new flight-training program called Flight School XXI. Wesolek (2007) estimated the cost to train a single aviator as ranging from $265,000 to $509,000. In 2005 the hourly cost per training aircraft at USAAWC was $924 for the TH-67, $942 for the OH-58, $2,760 for the UH-60, and $6,793 for the CH-47 (Wesolek).

Pate (1988) calculated the costs saved by Army aviation through the use of simulators for a part of aviator training. (Amounts in parentheses represent inflation-adjusted 2007 dollars.) Compared to live aircraft costs, use of the UH-1 flight simulator saved USAAVNC in excess of $50 million ($87.5 million) in cost avoidance annually. Training cost avoidance for the field was in excess of $41 million ($71.8 million) annually for the UH-1. At USAAVNC, use of the CH-47D flight simulator resulted in cost avoidance of more than $3 million ($5.3 million) annually. For the field, training cost avoidance attributable to this simulator was in excess of $24 million ($42 million) annually. Training cost avoidance annually attributable to the UH-60 flight simulator was in excess of $10 million ($17.5 million) at USAAVNC and $121 million ($211.8 million) in the field. The USAAVNC and field simulator for the AH-64A Apache is the Combat Mission Simulator (CMS). Annual cost avoidance figures for this device at USAAVNC were more than $13 million ($22.8 million) and more than $117 million ($204.8 million) in the field. Although the CMS allows the training of gunnery skills, these figures did not include ammunition costs. Cost avoidance calculations would be many times higher if ammunition costs were included.

The point of these comparisons is that Army aviation training is expensive; that training with live aircraft is many times more expensive per hr than simulator-based training; and that Army aviation training can save, and has already saved, many millions of dollars per year by using simulators for a part of required training. Simulator-based training to augment live-aircraft training is here to stay. Unfortunately, some aviators experience simulator-induced discomfort, or simulator sickness, when operating a flight simulator. It is simulator-induced discomfort that is the subject of this report.

Background

Reviews

With the growth of simulation for aviator training in the 1980s came a concomitant increase in simulator-induced motion sickness, which was labeled simulator sickness (SS). This problem was duly noted and became the justification for increased research into the magnitude, correlates, causes, and treatment of SS. The results of this work have been reviewed extensively. Crowley and Gower (1988) offered an introductory review for the experienced aviator. The books edited by McCauley (1984) and AGARD (1988) reviewed key areas of this research. Reviews by Kennedy and colleagues described the earlier research with special emphasis on the large Navy database (Kennedy, Berbaum, Allgood, Lane, Lilienthal, & Baltzley, 1988; Kennedy

et al., 1987; Kennedy & Frank, 1985; Lilienthal, Kennedy, Berbaum, Dunlap, & Mulligan, 1987). With the emergence of virtual environment technologies and helmet-mounted displays in the 1990s, the salience of the problem of SS increased again—and this time not just for aviation training but for consumer entertainment as well. Later reviews (Biocca, 1992; Ebenholtz, 1992; Kennedy & Fowlkes, 1992; Kennedy, Lane, Lilienthal, Berbaum, & Hettinger, 1992; Kolasinski, 1995, 1997; Pausch et al., 1992) expanded on the earlier reviews by including these newer technologies, where research was available, and addressing issues related to virtual reality. The review by Wright (1995) addressed the problem of SS in the training of Army helicopter pilots. The author has also reviewed this literature with special emphasis upon theory (Johnson, 2005).

Terminology and Distinctions

SS is a form of motion sickness (MS) that does not require true motion—but does require a wide field of view (FOV) visual display (Biocca, 1992; Mooij, 1988; Young, 2003). Like all varieties of MS, an intact vestibular system is necessary to experience SS (Ebenholtz, 1992). It has been called visually induced motion sickness (Benson, 1978; Reason & Brand, 1975; Pausch et al., 1992) and Cinerama sickness (Benson; Biocca; Reason & Brand). The term "vection" is used to describe a visually induced sense of self-motion. Vection is "… produced by the nearly uniform motion of a large part of the visual field… When the entire field moves, subjects soon begin to feel that the relative motion is their own" (Young, p. 98). Whether found in a flight simulator, theatre, or virtual reality simulation, vection causes a MS-like discomfort for a substantial minority of participants. This unpleasant experience is now universally referred to as SS. Further, these MS-like symptoms are now referred to as SS whether the simulator is a fixed-base model, and has no true motion, or a motion-base one with a (limited) range of movement. In other words, if the discomfort occurs in a simulator of any kind it will be called SS in the literature.

> Simulator sickness is a term used to describe the diverse signs or symptoms that have been experienced by flight crews during or after a training session in a flight simulator… Motion sickness is a general term for a constellation of symptoms and signs, generally adverse, due to exposure to abrupt, periodic, or unnatural accelerations. Simulator sickness is a special case of motion sickness that may be due to these accelerative forces or may be caused by visual motion cues without actual movement of the subject… (McCauley, 1984, p. 1)

A subtle distinction has been made between true MS and SS. MS is caused by motion. SS is caused by an inability to simulate the motion environment accurately enough (Kennedy et al., 1988; Kolasinski, 1995; Pausch et al., 1992). If a particular flight profile in an aircraft causes discomfort, this is MS. If the same profile is simulated veridically in a simulator, with the same physical forces present, and discomfort is caused, technically this is still MS. If a particular flight profile in the aircraft does not cause discomfort, but when simulated it does, this is SS. SS is discomfort produced in the simulator that does not occur when the same profile is executed in the physical motion environment. However, this is a logical distinction that apparently has no

practical significance. As before, if the discomfort occurs in a simulator it will be called SS in the literature.

Selected History

Signs and symptoms of MS have been produced by visual stimulation alone in persons with an intact vestibular system. "This problem has been known to ophthalmologists and optometrists since the 1840s as the disorder termed asthenopia..." (Ebenholtz, 1992, p. 302). Asthenopia remained a little-known optical disorder until 1956 when aviators began operating the first fixed-base (non-motion) helicopter simulator.

Miller and Goodson (1958, 1960). Bell Aircraft Corporation was contracted by the Navy to develop a helicopter simulator for training visual flight skills and hovering. During preliminary demonstrations at Bell, prior to delivery to the Navy, it was found "...that a large number of observers (mostly helicopter pilots) experienced some degree of vertigo during these demonstrations" (Miller & Goodson, 1958, p. 7). The observers commented that their discomfort stemmed from the lack of vestibular cues to motion available from the fixed-base device.

Upon installation at the Naval Air Station, Pensacola, two psychologists (Havron & Butler) conducted an initial training evaluation of the device. During this evaluation "... a questionnaire revealed that twenty-eight of thirty-six respondents experienced some degree of sickness" (Miller & Goodson, 1958, p. 8). These participants included flight instructors, students, and other personnel experienced both in the simulator and the helicopter. "The more experienced instructors seemed to be the most susceptible to these unpleasant sensations" (Miller & Goodson, p. 8). Sixty percent of the instructors reported SS symptoms, but only twelve percent of the students (Miller & Goodson, 1960). This SS usually occurred in the first ten minutes of a training session and frequently lasted for several hrs afterward. The incidence and severity of this SS "... became such a serious problem that it was felt that unless it can be remedied in some way the utilization of such simulators as training devices would be limited considerably" (Miller & Goodson, p. 8).

As a part of their evaluation, Miller and Goodson (1958) interviewed several of the instructors from the earlier Havron and Butler study. "One of these men had been so badly disoriented in the simulator that he was later forced to stop his car, get out, and walk around in order to regain his bearings enough to continue driving" (Miller & Goodson, p. 9). Miller and Goodson reported positive transfer of training from simulator to aircraft, albeit with a tiny sample size. Later Miller and Goodson conducted an experiment in an attempt to determine the effect of retinal disparity and convergence on SS in this device. They recruited 10 Navy enlisted men as participants. They were unable to find any effect of their independent variables upon SS and concluded that, due to large individual differences in the report of sickness, a "... great many more than ten subjects" (Miller & Goodson, p. 11) were needed to perform behavioral research on this phenomenon. They discussed problems with the device that caused several optical abnormalities. Specifically, Miller and Goodson (1960) noted visual distortions and conflicts that could have caused the SS, including blurring of the image, distorted size perspective, and distorted movement parallax. While Miller and Goodson concluded that the discomfort found

could have been caused by some combination of conflicts within the visual modality alone, they also reported that an inter-sensory conflict between vision and proprioception existed. Finally, they listed a number of advantages to using a simulator for aircraft training, including safety, weather independence, training for special missions, and large economic savings. However, the SS problem "…became so serious that it was one of the chief reasons for discontinuing the use of the simulator" (Miller & Goodson, p. 212).

The events described above represent the first published accounts of SS. Several of the issues identified at the dawn of SS research have remained issues throughout the history of the field. To wit:

1. A substantial percentage of the people who operate the simulator experience SS. This is not a trivial event for simulator-based training—especially for helicopter training.

2. The personnel with more experience in the aircraft appear to have an increased susceptibility to SS.

3. Conflicts both inter-sensory (visual/vestibular) and intra-sensory (visual/visual or vestibular/vestibular) are implicated as the cause of SS.

4. The aftereffects of SS can last for hrs.

5. Unless remedied in some way, SS will limit simulator-based training.

6. The Miller-Goodson anecdote. "One of these men had been so badly disoriented in the simulator that he was later forced to stop his car, get out, and walk around in order to regain his bearings enough to continue driving." This anecdote has been repeated frequently throughout the literature as evidence that safety issues are at stake in simulator-based training.

7. Sample size matters. Individual differences in susceptibility to, and reporting of, SS are so large that behavioral research requires large sample sizes.

8. Research shows positive transfer of training from the simulator to the aircraft for many tasks.

9. There are many advantages to simulator-based training besides positive transfer of training, including: safety, independence from (non-flyable) weather, the opportunity to train special missions (mission rehearsal), and large savings in the resources required for flight training.

McGuinness, Bouwman, and Forbes (1981). The Air Combat Maneuvering Simulator (ACMS) was installed at the Naval Air Station, Virginia Beach, in November 1979; it was commissioned in February 1980; and by March of 1980 reports of SS had found their way to the Naval Training Equipment Center for investigation (McGuinness et al.). The ACMS was a wide FOV, fixed-base, fixed-wing aircraft simulator designed to resemble the cockpits of F-4 and F-

14 fighters. Questionnaires were administered to 66 aviators during individual, confidential interviews. The aviators were either pilots or radar intercept officers with flight experience ranging from 250 to 4000 hrs. Each had four one-hr training sessions in the ACMS over a period of approximately one week.

Twenty-seven percent of the participants experienced at least one symptom of SS. The rate for participants with greater than 1500 flight hrs experience was 47%, while for those with 1500 or fewer hrs it was 18%. The ages of participants were not reported, nor were the incidence rates presented by age. The most common symptom reported was dizziness, followed by vertigo, disorientation, and nausea. There were no reports of flashbacks. Of those who reported symptoms of SS, 61% stated that these symptoms persisted between 15 minutes and 6 hrs. Of those who reported symptoms, all symptoms subsided completely after a night's rest. Thirty-three percent of the aviators reported that the reset function (freezing the visual display and returning to a new set of initial conditions) was the most probable cause of SS onset. There was some evidence of adaptation to the simulator over the course of several sessions. Finally, as a part of their literature review, the authors repeated the Miller-Goodson anecdote.

Several of the findings and explanations reported by McGuinness et al. (1981) have been replicated or cited in many other articles since then. To wit:

1. The authors explained the SS found in their study with reference to the sensory conflict theory. They argued that there was an inter-sensory conflict between the vection produced by the wide FOV visual display and the lack of any actual motion (vestibular stimulation) in the fixed-base simulator.

2. They explained the differential rate of SS as a function of flight experience, measured by flight hrs, in the same fashion. The relative sensory conflict would have been greater for the more experienced aviators because these aviators had a larger neural store of prior flight experience. Therefore, a larger conflict between the current pattern of sensory inputs and the expected pattern would translate into more SS. However, unlike many later researchers, McGuinness et al. did not ignore age entirely. They cited a report by Olive stating that susceptibility to vertigo and disorientation increased with increasing age of Naval aviators. They also stated:

   > Physiological body changes resulting from physical aging may also be a contributing factor to this phenomenon, since those with more flight hrs naturally tend to fall into older age groups. (McGuinness et al., 1981, p. 25)

3. The SS symptoms reported by the participants, though similar to MS symptoms, were not identical. There were more vision and disorientation symptoms and fewer gastrointestinal symptoms. That is, there was less nausea and no emesis.

4. The symptoms had abated after one night's rest.

5. The freeze/reset function was implicated as causal in producing SS.

6. There was some evidence of adaptation over repeated simulator sessions.

McCauley (1984). McCauley described several potential operational problems that could result from SS. This discussion (McCauley's four points) was quickly adopted and repeated by later authors.

> 1. Compromised Training. Symptoms experienced in the simulator may compromise training through distraction and decreased motivation. Behaviors learned in the simulator to avoid symptoms (e.g., not looking out the window, reducing head movements, avoiding aggressive maneuvers) may be inappropriate for flight.
> 2. Decreased Simulator Use. Because of the unpleasant symptoms and aftereffects, simulator users may be reluctant to return for subsequent training sessions. They also may have reduced confidence in the training they receive from the simulator.
> 3. Ground Safety. Aftereffects, such as disequilibrium, could be potentially hazardous for users when exiting the simulator or driving home.
> 4. Flight Safety. No direct evidence exists for a relationship between simulator sickness aftereffects and accident probability. However, from the scientific literature on perceptual adaptation, one could predict that adaptation to a simulator's rearranged perceptual dynamics would be counterproductive in flight. (McCauley, 1984, pp. 2-3)

These issues were discussed as potentially important operational problems. For those who work in the field of simulator-based flight training, it is not a stretch to imagine that SS can affect safety and training. This possibility was noticed immediately (Miller & Goodson, 1958, 1960). However, note that McCauley explicitly stated that there was "no direct evidence" suggesting simulators are causally implicated in aircraft accidents. McCauley's four points appear frequently in published reports of SS.

Crowley (1987). In August 1984 the AH-1 Cobra Flight Weapons Simulator (FWS) became operational at Hanau U.S. Army Airfield in Germany. Soon thereafter reports of pilots becoming ill were made to Dr. Crowley, a flight surgeon at Hanau. The FWS was a motion-base simulator, employing a terrain board database, and moderately narrow FOV visual displays (48 degrees horizontal gunner station, 96 degrees horizontal pilot station). Anonymous questionnaires were administered to 115 Army Cobra pilots who were training using the FWS simulator at Hanau. One hundred twelve (112) questionnaires were returned (97%).

Forty percent of the participants reported at least one symptom of SS. Nausea was the most frequent symptom, followed by sweating, and dizziness. Three pilots (3%) reported vomiting. Pilots who reported SS symptoms had significantly more total flight time than those who did not report symptoms. Pilots with greater than 1,000 hrs of Cobra flight time were significantly more likely to report SS than pilots with fewer than 1,000 hrs. Experience in the

FWS was significantly and negatively correlated with reported SS. That is, more simulator time in the FWS was associated with fewer reports of SS symptoms. Crowley (1987) explained these results in terms of the sensory conflict theory. He quoted the Miller-Goodson anecdote. He also discussed McCauley's four points and observed that any negative effects of SS upon training remained to be documented.

Because Crowley believed SS to be a potential hazard to aviation safety, a mandatory grounding policy was instituted at Hanau Army Airfield. The most significant portions of the Hanau policy were:

> Aviators flying the AH-1 Flight Weapons Simulator (FWS) are medically restricted from flying duties until the beginning of the next duty day, (normally 0630-0730)… Any aviator forced to stop a simulator period early due to motion sickness is grounded until seen by a flight surgeon and returned to flying duty. (Crowley, 1987, p. 357)

Signs and Symptoms

SS is polysymptomatic (Kennedy & Fowlkes, 1992; Kennedy & Frank, 1985; Kennedy, Lane, Berbaum, & Lilienthal, 1993). Symptoms include nausea, dizziness, spinning sensations, visual flashbacks, motor dyskinesia, confusion, and drowsiness (McCauley, 1984). Observable signs of SS include pallor, cold sweating, and emesis (McCauley). The standard measurement instrument for SS, the Simulator Sickness Questionnaire (Kennedy, Lane, et al.), lists 16 symptoms: general discomfort, fatigue, headache, eyestrain, difficulty focusing, increased salivation, sweating, nausea, difficulty concentrating, fullness of head, blurred vision, dizzy (eyes open), dizzy (eyes closed), vertigo, stomach awareness, and burping. Reports of visual flashbacks and visual hallucinations have been documented (McCauley; Wright, 1995; Young, 2003) although they are rare.

The signs and symptoms listed above overlap with those reported for MS (Benson, 1978; Reason & Brand, 1975). However, there are several differences. The most consistently reported difference is that while major symptoms of MS involve gastrointestinal distress (e.g., burping, stomach awareness, nausea, emesis), for SS there are fewer gastrointestinal symptoms and more visual ones, such as eyestrain, difficulty focusing, blurred vision, and headache (e.g., Kennedy et al., 1988; Kennedy & Fowlkes, 1992; Kennedy, Lane, et al., 1993; Kennedy, Lane, et al., 1992; Lilenthal et al., 1987; Uliano, Lambert, Kennedy, & Sheppard, 1986). Vomiting is a common sign of MS. For example, 75 percent of those suffering from seasickness vomit (Kennedy & Fowlkes, 1992). By comparison, vomiting is rare in SS—usually occurring in less than one percent of the cases (Kennedy & Fowlkes, 1992; Kennedy, Lane, et al., 1993). Finally, in cases of vection-induced SS, such as a fixed-base flight simulator, closing one's eyes will end the perceived motion and dramatically reduce the symptoms (Kennedy, Lane, et al., 1993). Closing one's eyes, however, will have no such effect on MS.

Helicopter simulators have been widely reported to produce more SS than fixed-wing simulators (Baltzley, Kennedy, Berbaum, Lilienthal, & Gower, 1989; Kennedy et al., 1988;

Kennedy, Lane, et al., 1992; Kennedy et al., 1989; Wright, 1995; Young, 2003). This is probably because helicopters are usually flown closer to the ground. Discomfort level varies inversely with height above terrain (Kennedy & Fowlkes, 1992; Kolasinski, 1995; Wright). There is a greater perception of visual flow, caused by greater visual detail, at lower height above terrain.

Several reports of original research include a listing of the most common symptoms found in helicopter simulators. Gower and Fowlkes (1989a) reported a study of the Cobra AH-1 FWS. This device incorporated a six-degree of freedom (6-DOF) motion base. (These six dimensions of motion are pitch, roll, yaw, vertical [heave], lateral [sway], and longitudinal [surge]). The most commonly reported symptoms from Gower and Fowlkes were eyestrain (37% of the participants) and fatigue (27%).

Gower, Lilienthal, Kennedy, Fowlkes, and Baltzley (1987) reported on another simulator of an attack helicopter. This was the CMS for the Apache AH-64A. The CMS is an interactive, full-mission, 6-DOF simulator. The most commonly reported symptoms were fatigue (43% of participants), sweating (30%), and eyestrain (29%). Braithwaite and Braithwaite (1990) reported on a simulator for the British attack helicopter the Lynx. This device included a 6-DOF motion system with a 130 degree (horizontal) by 30 degree (vertical) FOV color projection visual system. The most commonly reported symptoms were disorientation (24% of participants) and difficulty focusing (24%).

Gower and Fowlkes (1989b) studied the SS potential of a simulator for the UH-60 Blackhawk utility helicopter. This device incorporated a 6-DOF motion base plus forward, left, and right out-the-window views from a collimated visual display. The most common symptoms were fatigue (35% of participants) and eyestrain (34%). Silverman and Slaughter (1995) reported on an operational flight trainer for the MH-60G PAVE Hawk helicopter. This was a fixed-base device. It provided a 150 degree (h) by 40 degree (v) out-the-window visual display plus two chin window displays. The most commonly reported symptoms were stomach awareness, dizziness, nausea, fatigue, and sweating in descending order of frequency.

Gower, Fowlkes, and Baltzley (1989) reported on the SS symptoms produced by the full-mission simulator model 2B31 for the CH-47 Chinook cargo helicopter. This was a 6-DOF motion device with a 48 degree (h) by 36 degree (v) forward visual display plus a 22 degree (h) by 30 degree (v) chin window display. The most commonly reported symptoms of SS were fatigue (34% of participants), eyestrain (29%), headache (17%), difficulty focusing (13%), sweating (11%), nausea (9%), and stomach awareness (9%).

Measurement

Several reviews discussed the difficulties with and tools for measuring SS (Casali & Frank, 1988; Hettinger, Nolan, Kennedy, Berbaum, Schnitzius, & Edinger, 1987; Kennedy & Fowlkes, 1992; Kolasinski, 1995). Because SS is polysymptomatic one cannot measure just one dependent variable (Kennedy & Fowlkes). Another measurement difficulty is that there are large individual differences in susceptibility to SS. It is common in this research to find that fully 50 percent of simulator operators experience no symptoms at all (Kennedy & Fowlkes). When

effects of SS exist, they are often small, weak effects that disappear quickly upon exiting the simulator. Further, because most participants eventually adapt to the motion environment of a particular simulator, researchers cannot reuse the same participants (such as in a within-subjects research design). Thus, researchers are forced to employ between-subjects research designs (Kennedy & Fowlkes). When one combines these factors of large individual differences, weak effects, adaptation, and between-subjects designs it invariably leads to the conclusion that research into SS requires large sample sizes. To get samples of this large size, researchers survey pilots training in simulators at military training centers (Kennedy & Fowlkes). However, these centers exist to train pilots, not to perform research. This means that the level of experimental control exercised by a researcher is usually low. So research investigating SS employs either vast surveys of nearly all pilots operating a particular simulator at a particular facility at a particular time, or small-scale experiments with more control but smaller sample sizes.

There are a number of possible ways to measure SS (Casali & Frank, 1988; Hettinger et al., 1987). One could employ direct observation of participants during a simulator session and note signs such as facial pallor and sweating. This is seldom done for research measurement (cf., Uliano et al., 1986), but often used by instructors at the simulator site to monitor their students. Another option would be self-report measures, such as the Simulator Sickness Questionnaire, that ask the participant to note the type and severity of symptoms currently being experienced. This method is universally performed in some fashion. A third option would be to instrument the participants and measure physiological conditions such as respiration rate and stomach activity. This method has been used upon occasion. Finally, one can employ tests of postural equilibrium to measure simulator-induced disorientation or ataxia. These tests have been widely employed, but with equivocal results.

Simulator Sickness Questionnaire (SSQ). The SSQ is currently the gold standard for measuring SS. This instrument was developed and validated by Kennedy, Lane, et al. (1993). The SSQ was developed based upon 1,119 pairs of pre-exposure/post-exposure scores from data that were collected and reported earlier (Baltzley et al., 1989; Kennedy et al., 1989). These data were collected from 10 Navy flight simulators representing both fixed-wing and rotary-wing aircraft. The simulators selected were both 6-DOF motion and fixed-base models, and also represented a variety of visual display technologies. The SSQ was developed and validated with data from pilots who reported to simulator training healthy and fit.

The SSQ is a self-report symptom checklist. It includes 16 symptoms that are associated with SS. Participants indicate the level of severity of the symptoms that they are experiencing currently. For each of the symptoms there are four levels of severity (none, slight, moderate, severe). The SSQ provides a Total Severity score as well as scores for three subscales (Nausea, Oculomotor, and Disorientation). The Total Severity score is a composite created from the three subscales. It is the best single measure because it provides an index of the overall symptoms. The three subscales provide diagnostic information about particular symptom categories. The Nausea subscale is made up of symptoms such as increased salivation, sweating, nausea, stomach awareness, and burping. The Oculomotor subscale includes symptoms such as fatigue, headache, eyestrain, and difficulty focusing. The Disorientation subscale is composed of symptoms such as vertigo, dizzy (eyes open), dizzy (eyes closed), and blurred vision. The three

subscales are not orthogonal to one another. There is a general factor common to all of them. Nonetheless, the subscales provide differential information as to symptomatology and are useful for determining the pattern of discomfort produced by a given simulator. All scores have as their lowest level a natural zero (no symptoms) and increase with increasing symptoms reported.

An important advantage of the SSQ is that a wide variety of symptoms can be measured quickly and easily with the administration of this one questionnaire. Another important advantage is that it allows quantitative comparisons across simulators, populations, and within the same simulator over time (as a diagnostic to determine if recalibration is needed).

However, Kennedy, Lane, et al., (1993) stated restrictions in the use of the SSQ also. First, the SSQ is not to be used with participants who are in other than their usual state of health and fitness. The instrument was developed and validated based on data from healthy, fit pilots. Any scores obtained from participants who arrived for simulator training ill would be uninterpretable. Second, the authors recommended that the SSQ be administered immediately after a simulator session, but not before one. They did not recommend using pre-post difference scores. This is because the high correlation usually found between pre and post scores can render the difference scores unreliable. Nonetheless, researchers sometimes report pre-post difference scores anyway (e.g., Regan & Ramsey, 1996).

Instrumented physiological measures. Another method for measuring SS is to record physiological changes directly during simulator use.

> Changes in bodily cardiovascular, gastrointestinal, respiratory, biochemical, and temperature regulation functions often arise with simulator sickness. Several physiological measures have been electronically or electro-optically instrumented and transduced directly from subjects in simulator experiments. (Casali & Frank, 1988, pp. 9-10)

Heart rate, or pulse rate, has been reported to change from baseline levels as a function of simulator exposure (Casali & Frank, 1988). Unfortunately these reported changes are not sensitive, reliable, or always in the same direction. Respiration rate has proven to be a sensitive index of SS (Casali & Frank). However, the direction of the change is not consistent across individuals. As with MS (Reason & Brand, 1975), some individuals increase respiration rate upon simulator exposure, while others decrease rate. Casali and Frank recommend using an absolute difference score. Sweating is a common symptom of SS and this can be measured as an increase in skin conductance or a decrease in skin resistance (Casali & Frank). Facial pallor is also a common symptom of SS. Paleness of the skin can be measured using photo-optical sensors and has been shown to vary as a function of conditions that cause SS (Casali & Frank). Gastric activity can be measured with an electrogastrogram. Gastric activity in the form of tachygastria, a dramatic increase in stomach motility, has been shown to occur along with other symptoms of SS during exposure to vection (Casali & Frank; Hettinger et al., 1987).

Tests of postural equilibrium. Reviews of this methodology can be found in Casali and Frank (1988), Kennedy, Berbaum, and Lilienthal (1997), and Kolasinski (1995). Postural

equilibrium tests (PETs) exist to provide a behavioral measure of ataxia. Ataxia is a potentially dangerous symptom. In the domain of SS research, ataxia is defined as postural instability, postural unsteadiness, or postural disequilibrium (e.g., Kennedy et al., 1997; Kolasinski & Gilson, 1999). It is thought that any disruption of balance and coordination that results from exposure to a simulator may be a safety concern for pilots who need to walk, climb stairs, drive, or fly after a simulator training session. The PETs are used to provide a direct index of postural instability.

> Loss of balance and ataxia are common problems noted by trainees and subjects after exiting a dynamic simulator. The simulator presents an altered sensory environment which usually entails considerable vection, and some adaptation to this environment occurs in the operator's visual and vestibular sensory systems. Upon return to the "normal" environment, balance and equilibrium may be disrupted until the person progresses through re-adaptation. Such effects may be measured using pre-post simulator postural equilibrium tests. (Casali & Frank, 1988, p. 14)

There are several PETs that are described in the literature. They all involve some permutation of the following procedures: standing heel to toe with eyes closed and arms folded across the chest or back; or standing on one leg (preferred leg or non-preferred leg) with eyes closed or open and arms folded across the chest; or walking a straight line (on floor or rail) heel to toe with eyes closed or open and arms folded across the chest. The names and acronyms, where available, for several PETs are listed: Sharpened Romberg (SR), Stand on One Leg Eyes Closed (SOLEC), Stand On Preferred Leg Eyes Closed (SOPLEC, SOPL), Stand On Non-preferred Leg Eyes Closed (SONLEC, SONL), walk toe to heel, Walk On Floor Eyes Closed (WOFEC), Walk On Line Eyes Closed (WOLEC), and Walk On Rail Eyes Open (WOREO).

An example of a method for using PETs in research is described below:

> *Standing on Preferred Leg (SOPL)*: This test of standing steadiness required pilots to first determine which leg they preferred to stand on. Pilots were asked to stand, fold their arms against their chest, close their eyes, lift their non-preferred leg and lay it about two-thirds of the way up the standing leg's calf. They attempted to remain in that position for 30 s. If they moved their pivot foot, moved their raised foot away from their standing leg, grossly lost their erect body position, the trial ended and the time up to that point (in seconds) was recorded as the score for that trial.
> *Standing on Non-Preferred Leg (SONL)*: The procedure for this test was identical to that of the SOPL test except that pilots stood on their non-preferred leg. (Kennedy et al., 1997, p. 15)

The research literature shows mixed results when using PETs to demonstrate an effect of simulator exposure upon postural stability. Some studies have found no statistically significant

effect of simulator exposure upon performance of PETs (Gower & Fowlkes, 1989b; Gower et al., 1989; Hamilton, Kantor, & Magee, 1989; Lampton et al., 1995; Uliano et al., 1986). Other studies have found a statistically significant effect for some or all PETs used (Duh, Parker, & Furness, 2001; Gower & Fowlkes, 1989a; Gower et al., 1987; Kennedy, Fowlkes, & Lilienthal, 1993; Lerman, Sadovsky, Goldberg, Kedem, Peritz, & Pines, 1993; Warner, Serfoss, Baruch, & Hubbard, 1993).

There are several differences among the reports cited above, and viable explanations for the equivocal results readily present themselves. As mentioned above with regard to SS in general, if an effect is highly subject to individual variability then large sample sizes are required. The mean sample size for the five studies listed above that did not report a significant difference was 61. For the six studies that reported positive results the mean sample size was 120. One cause of variability in performance can be differential rates of learning. Hamilton et al. (1989) demonstrated significant learning effects in the performance of four PETs (SR, SOLEC, WOREO, WOLEC). Further, performance on these four PETs continued to improve over the 10 practice sessions they measured. Therefore, when using PETs one must be aware that any improvement in performance occasioned by learning will tend to mask any decrement in performance caused by simulator exposure—if such a decrement exists.

Finally, Kennedy et al. (1997) found a statistically significant correlation between the Disorientation subscale of the SSQ and performance measures taken from two PETs (SOPL, SONL). The higher the Disorientation scores on the SSQ, the poorer the performance on the two PETs. In other words, the subjective self-reports of the pilot participants accurately reflected the behavioral measures taken from them after exiting the simulators. Given the potential measurement problems associated with PETs, the time and effort required in their administration, and the fact that similar results can be acquired more easily and quickly with the SSQ, the use of tests of postural equilibrium should probably be limited to research questions where their specific contribution is necessary.

Research Results Using the SSQ to Measure Simulator Sickness

Table 1 presents the results of using the SSQ to measure the severity of SS symptoms after exposure to a variety of aircraft simulators. The index used in each case was the Total Severity (SSQ-TS) score described above. There are a few points to be noted from Table 1. First, the mean SSQ-TS scores were not zero even prior to exposure to the aircraft simulator. These scores ranged between 4.02 and 6.03 prior to simulator exposure. The participants operating aircraft simulators are usually pilots taking part in simulator-based training. They commonly report slight symptoms (usually "fatigue") even before climbing into the simulator cockpit. Second, the reported range of exposure durations varied between 90 and 120 min. Finally, the mean post exposure SSQ-TS scores ranged between 1.50 and 20.15.

Table 1

SSQ Total Severity Scores from Participants Exposed to Selected Aircraft Simulators

Publication	Simulator (Aircraft)	*N*	Exposure Duration	SSQ-TS Pre	SSQ-TS Post
Durbin, Havir, Kennedy, & Pomranky (2003) (Table 16)	CPC (RAH-66)	8	90 min	4.02	11.40
	EDS (RAH-66)	8	90 min	4.02	13.25
Durbin & Hicks (in preparation) (Table 5)	ARH Crewstation (ARH)	6	90 min	6.03	20.15
Johnson (current report)	STRATA (AH-64A)	474	90 min	4.59	12.73
Kennedy, Berbaum, Smith, & Hettinger (1992) (Figures 2, 3)	(Five Navy & Marine helos)	---	---	---	12 - 18
Kennedy, Drexler, Compton, Stanney, Lanham, & Harm (2003) (Figures 12.2, 12.6)	(Eight military helicopters)	3000 total	---	---	12.63
Kennedy, Lane, Berbaum, & Lilienthal (1993) (Table 6)	2F64C (SH-3)	1000 total	---	---	18.80
	2F120 (CH-53F)		---	---	10.00
	2F121 (CH-53D)		---	---	7.50
	2F117 (CH-46E)		---	---	7.00
	2F110 (E-2C)		---	---	10.30
	2E7 (F/A-18)		---	---	6.80
	2F87F (P-3C)		---	---	10.50
	2F132 (F/A-18)		---	---	4.20
	2F112 (F-14)		---	---	1.50
Stoffregen, Hettinger, Haas, Roe, & Smart (2000) (Table 2)	SIRE (F-16)	14	120 min	5.08	19.51

Using the SSQ, simulators (or training techniques, or exposure durations) can be compared on the extent to which they produce discomfort. Table 1 is an example of such a comparison. High scores are an index of more reported discomfort than are low scores. But what do these scores mean? What is a low score? What is a score that is unacceptably high? Kennedy, Drexler, Compton, Stanney, Lanham, and Harm (2003) provided a categorization of symptom scores based on several thousand exposures of military aviators to aircraft simulators. Their classification is presented below:

- 0 No symptoms
- < 5 Negligible symptoms
- 5 – 10 Minimal symptoms
- 10 – 15 Significant symptoms
- 15 – 20 Symptoms are a concern
- > 20 A problem simulator

Table 2 presents the results of using the SSQ to measure the severity of SS symptoms after exposure to several virtual environment (virtual reality) systems—all of which employ a helmet-mounted or head-mounted visual display (HMD). In each case the index used was the same SSQ-TS score described above. Note, again, that the mean scores ranged between 3.74 and 7.10 prior to exposure. The range of mean post-exposure SSQ-TS scores was 16.85 to 41.51. Six of the eight mean post-exposure scores were greater than 20, indicating "a problem simulator" (Kennedy et al., 2003, p. 256). The remaining two mean scores were approximately 17, indicating that the "symptoms are a concern" (Kennedy et al., p. 256). Interestingly, these relatively high symptom scores were obtained with exposure durations that were shorter than is usual in simulator-based aviation training (compare Table 1 with Table 2). The propensity of virtual environment systems to cause relatively high levels of SS at relatively short exposure durations has been noted before (e.g., Biocca, 1992; Kennedy et al., 2003; Kolasinski, 1997; Pausch et al., 1992). However, a detailed analysis of the effects of virtual environment systems on the reported discomfort levels of experimental participants is beyond the scope of this report. The purpose of this section is only to show how the SSQ makes possible comparisons such as those shown in Tables 1 and 2.

Table 2

SSQ Total Severity Scores from Participants Exposed to Selected Virtual Environment Systems

Publication	$\underline{N}$	Exposure Duration	SSQ-TS Pre	SSQ-TS Post
Johnson (1997) (Table 5)				
• Wide FOV HMD	10	60 min	---	41.51
• Narrow FOV HMD	10	60 min	---	25.81
Kennedy, Drexler, Compton, Stanney, Lanham, & Harm (2003) (Figure 12.6)				
• Review of 8 VE studies	431 total	20 – 40 min	---	28.00
Knerr, Lampton, Singer, Witmer, Goldberg, Parsons, & Parsons (1998) (Table 5)	513 total	20 – 60 min with breaks	---	25.01
• Review of 13 VE experiments				
Kolasinski & Gilson (1999) (Table 1)	40	20 min	3.74	21.22
Prothero, Draper, Furness, Parker, & Wells (1999) (Table 1, Figure 2)				
• Experiment 1	15	6 min	---	16.85
• Experiment 2	21	9 min	7.10	16.85
Regan & Ramsey (1996) (Figure 4)				
• Placebo group	20	20 min	7.00	24.50

Incidence

The incidence of SS varies widely across simulators and conditions. A common method of presenting incidence is to list the percentage of participants who reported at least one symptom. In the review by McCauley (1984) incidence was reported to range from 10 to 88 percent. In their review Kennedy and Frank (1985) reported that incidence ranged from 27 to 88 percent. In later reviews Kennedy and colleagues (Kennedy et al., 1987; Kennedy & Fowlkes, 1992) reported that the incidence of SS ranged from 12 to 60 percent in Navy flight simulators. Pausch et al., (1992) reported in their review that it could range from 0 to 90 percent in flight simulators. Wright (1995) limited his review to helicopter flight simulators. He reported that the incidence ranged from a low of 13 percent, when a strict criterion was employed to define SS, to a high of 70 percent, when a lax criterion was used.

It is widely reported that simulators of rotary-wing (RW) aircraft cause participants more SS than simulators of fixed-wing (FW) aircraft. Assuming a constant criterion of at least one reported symptom, there are several studies that report incidence by simulated aircraft type. Kennedy and colleagues (Kennedy et al., 1988; Kennedy et al., 1989) collected data from 1,186 simulator exposures. Their sample included data from 10 flight simulators. These simulators represented both FW and RW aircraft, and included both motion-base and fixed-base models. The incidence rates for FW simulators ranged from 10 to 47 percent. The rates for RW simulators ranged from 26 to 69 percent. Baltzley et al. (1989) collected data from 742

exposures using a self-report questionnaire. Their sample included data from operators of 11 flight simulators (7 FW, 4 RW). All participants had experience training in flight simulators. The incidence rates reported by pilots training in FW simulators ranged from 6 to 62 percent. The rates reported by pilots training in helicopter simulators ranged from 48 to 57 percent. These results have the advantages of large sample sizes, multiple flight simulators, and a constant method of research and analysis performed by the same investigators.

Magee, Kantor, and Sweeney (1988) collected data from a sample of 42 C-130 pilots and flight engineers. The C-130 Hercules is a multi-engine, propeller-driven, FW, cargo aircraft. The C-130 simulator included a 6-DOF motion base and a 120 degree (h) by 40 degree (v) FOV visual display. Participants performed a four-hr simulator session with a short break at the mid-point. Ninety-five percent (95%) of the participants reported at least one symptom of SS upon exiting the simulator.

Crowley (1987) reported an incidence rate of 40 percent for the RW Cobra FWS. Braithwaite and Braithwaite (1990) reported an incidence rate of 60 percent for 183 Lynx helicopter crewmembers that returned self-report questionnaires. Gower et al. (1987) collected data from 127 participants training in the AH-64 CMS. This simulator represents the AH-64A Apache helicopter. An incidence rate of 44 percent was reported. Gower and Fowlkes (1989a) collected data from 74 Army aviators training in the Cobra FWS. Thirty-seven percent of the participants reported at least one symptom of SS. All four of the studies described in this paragraph reported results obtained from participants operating 6-DOF motion-base devices that simulated attack helicopters.

Lerman et al. (1993) collected data from 59 armor Soldiers performing tank driver training in a 3-DOF (pitch, roll, yaw) tank simulator. Sixty-eight percent of this sample reported at least one symptom of SS. Using the SSQ, Lampton et al. (1995) measured SS in an M-1 tank driver simulator mounted on a 6-DOF motion platform. They also measured discomfort in the actual M-1 tank. The authors reported significantly greater symptom scores in the simulator than in the tank. Upon interview, 36 percent of their sample reported experiencing discomfort in the simulator. The authors also reviewed the training records of six armor companies that had experienced the device previously. They found that 25 percent of these training records documented SS among the prior trainees. It is plausible that these incidence rates reported by Lampton and colleagues are conservative estimates. Instructors are not likely to mention SS in a written training document unless it is a significant phenomenon.

SS also exists in virtual reality (VR) simulators. For a review of SS from this perspective see Kolasinski (1995). Regan and Ramsey (1996) reported a 75 percent incidence rate for subjects in the placebo control group of a VR drug experiment. This level of discomfort was produced by a 20-minute immersion in the VR simulator. Kolasinski and Gilson (1999) immersed 40 research participants in a commercially available VR simulator for 20 minutes. Eighty-five percent of the participants reported at least one symptom of SS. It was because of high sickness rates such as these, produced by relatively short simulator sessions, that the practical future of VR technology became a subject of discussion (e.g., Biocca, 1992; Knerr et al., 1998; Kolasinski, 1997; Pausch et al., 1992).

It is clear from the literature reviewed above that the incidence of SS varies within a large range. Depending upon the simulator, the conditions of operation, and the criterion definition applied, the rate of SS can vary from low to extremely high.

Residual Aftereffects

The potential for dangerous aftereffects of simulator exposure—including ataxia, loss of balance, flashbacks—has been noted right from the beginning, as previously discussed (Miller & Goodson, 1958, 1960). In fact, the careful reader will meet the Miller-Goodson anecdote frequently in the literature—either quoted directly (e.g., Crowley, 1987; McCauley, 1984; McGuinness et al., 1981; Pausch et al., 1992; Wright, 1995) or, more often, referred to obliquely. McCauley's four points—two of which concern safety—are ubiquitous. Virtually every report refers in some way to these points. So researchers have done their part to alert the community of the potential for dangerous aftereffects of simulator-based flight training.

However, it is only prudent to assure the reader that this potential danger has not manifested itself objectively. Many of the same authors reported that there were no documented cases of flight incidents or automobile accidents linked to prior simulator-based training (Crowley, 1987; Kennedy & Frank, 1985; McCauley, 1984; Wright, 1995).

Baltzley et al. (1989) reported data from a large study involving 742 simulator exposures across 11 Navy and Army simulators. Overall, 45 percent of the participants reported experiencing symptoms of SS upon exiting the simulator. Of these pilots who reported symptoms, 75 percent said that their symptoms disappeared within 1 hr. Six percent reported that their symptoms dissipated in 1 to 2 hrs, 6 percent in 2 to 4 hrs, 5 percent in 4 to 6 hrs, and 8 percent reported that their symptoms lasted longer than 6 hrs. The most common category of aftereffect was nausea (51%), followed by disorientation (28%), and oculomotor (21%).

Braithwaite and Braithwaite (1990) reported that 17 percent of their sample experienced aftereffects. The most frequently stated aftereffects were nausea, which dissipated in 2 hrs, and headache, which sometimes lasted as long as 6 hrs. Crowley (1987) reported that 11 percent of his sample experienced delayed effects of simulator training. The most commonly reported delayed symptom was a perception of illusory movement. Gower et al. (1987) reported aftereffects following training in the Apache CMS. Over a series of 10 training sessions, preflight minus postflight performance on 3 PETs decreased until session number 4 and then remained stable for the remainder of the simulator periods. This was interpreted as behavioral evidence of increasing simulator-induced disequilibrium over training trials.

McGuinness et al. (1981) reported that 18 members of their sample of 66 aviators (27%) experienced at least one symptom of SS. Of these 18, 11 (61%) stated that their symptoms persisted anywhere from 15 minutes to 6 hrs. Silverman and Slaughter (1995) reported results from participants operating a wide FOV, fixed-base MH-60G operational flight trainer for the PAVE Hawk helicopter. Data were collected in conjunction with an operational test and evaluation of the simulator. Sortie lengths were at least 3 hrs and included a full range of flight tasks. A total of 13 experienced aviators participated and filled-out self-report questionnaires. Eight of these 13 participants (62%) reported at least one symptom aftereffect. The most

commonly reported aftereffects were fatigue, stomach awareness, and vertigo, in that order. Most of these aftereffects came and went within 2 hrs of exiting the simulator, although some participants reported symptoms lasting up to "…several hours after the simulator training session" (Silverman & Slaughter, p. 11).

There are some crude conclusions that emerge about the aftereffects of simulator exposure. First, approximately 10 percent of the sample will experience pronounced aftereffects (Kennedy et al., 1988; Kennedy & Fowlkes, 1992). Second, there is a significant positive correlation between the number and severity of symptoms reported immediately upon leaving the simulator, and the duration and severity of aftereffects (Chappelow, 1988; Silverman & Slaughter, 1995). That is, those who experience the most SS during the simulator session usually experience the most aftereffects later. Third, the aftereffects of simulator exposure usually wear off in an hr or two. The persistence of symptoms longer than 6 hrs has been documented, but fortunately remains statistically infrequent.

It is understood in the training community that a potential exists for residual aftereffects to be a risk to flight safety. For this reason, guidelines recommending a mandatory grounding policy after training in a flight simulator have appeared both in the research literature and the training environment (Chappelow, 1988; Crowley, 1987; Crowley & Gower, 1988; Kennedy et al., 1988; Kennedy et al., 1987; Kennedy, Lane, et al., 1992; Lilienthal et al., 1987; NTSC, 1988). The minimum recommended period from simulator to aircraft has ranged from 6 to 12 hrs and usually includes the admonition to wait until the next day. In cases of severe discomfort, curtailment of other duties for 24 hrs has been recommended (Kennedy et al., 1988).

> Allowing a night's sleep before recommencing flying duties should reduce residual risks to negligible proportions. (Chappelow, 1988, p. 10)

> During initial simulator training sessions or after a long period of not using the simulator, avoid scheduling simulator and aircraft flights on the same day. (NTSC, 1988, p. 8)

Adaptation

It is well established that MS usually disappears with repeated exposures to the sickness-producing environment (Benson, 1978, 1988; Biocca, 1992; Kennedy & Frank, 1985; Reason, 1978; Reason & Brand, 1975; Young, 2003). This reduction in symptoms with experience in the provocative environment is called "adaptation" (sometimes "habituation"). Between 95 and 97 percent of people studied eventually adapt to the novel motion environment (Biocca; Reason & Brand). The remainder never adapt, regardless of the length of their exposure, and remain chronically motion sick. Laboratory studies show large differences in rates of adaptability among individuals, and also that these adaptability rates are a consistent trait for each individual (Reason & Brand). Most people adapt to a new motion environment fairly quickly, many people require a very long time to adapt, and a small percentage of unfortunates never adapt.

The concept of adaptation in the literature of SS is identical to that in the literature of MS. Several reviewers have discussed adaptation to a novel simulated motion environment (Biocca, 1992; Crowley & Gower, 1988; Kennedy & Fowlkes, 1992; Kennedy & Frank, 1985; Kolasinski, 1995; Wright, 1995). Most participants adapt to the simulator after approximately six sessions (Biocca; Kennedy, Lane, et al., 1993; Wright).

Crowley (1987) found that there was a statistically significant inverse relationship between the prior number of hrs spent training in the Cobra simulator and the amount of SS reported. The more prior exposure to the simulator, the less SS was experienced by the pilots. This was interpreted as evidence of adaptation. Gower and Fowlkes (1989a) reported the same inverse relationship with a different sample of Cobra pilots and another FWS. Gower et al. (1989) reported a significant negative correlation between prior history of hrs spent training in the CH-47 flight simulator and SS for a sample of experienced CH-47 pilots. Gower et al. (1987) investigated the effects of exposure to the AH-64A CMS on discomfort levels for 127 Apache aviators. Over the course of 10 training sessions, they found that self-reported SS symptoms decreased with increasing sessions in the CMS. They also reported an inverse relationship between the amount of simulator exposure during the prior three months and SS. Finally, they noted a significant negative correlation between the amount of recent CMS exposure and disequilibrium as measured by a PET. These results were interpreted as evidence of adaptation to the CMS.

Silverman and Slaughter (1995) reported evidence of adaptation to a MH-60G operational flight trainer for the PAVE Hawk helicopter. A sample of 13 experienced pilots executed a full range of flight tasks over several sessions in the simulator. The number of SS symptoms reported on later days was significantly fewer than the number reported on the first day of testing. Uliano et al. (1986) required 25 experienced pilots to operate the Vertical Take-off and Landing (VTOL) simulator which represents the SH-60B Seahawk helicopter. Each pilot flew the same flight paths, and performed the same tasks under the same experimental conditions, in counter-balanced order, over 3 days. SS was reported to be significantly worse on day 1 than day 2, and significantly worse on day 2 than day 3. The authors interpreted these results as evidence of adaptation to the simulator.

Besides reviewing the SS literature, Wright (1995) reported on his interviews with Army helicopter flight instructors. These instructors trained helicopter pilots daily. Yet, when introduced to a new simulator, they experienced SS symptoms. After a few days the symptoms disappeared or at least subsided to a minor and tolerable level. These instructors also reported that after several months away from the simulator, they had to readapt as if for the first time. Then readapt they did, again, in a few sessions. Wright interpreted these statements as evidence of adaptation to a novel (simulated) motion environment.

All of the studies cited above involved aviators adapting to a helicopter flight simulator of some kind. Lampton et al. (1995) reported evidence of adaptation to an M-1 tank driver trainer. They collected data from 115 trainees, all of whom had no prior experience driving a tank. Over the course of several training sessions the amount of SS the trainees experienced decreased. The symptom scores, as measured using the SSQ, were significantly higher after the

first training session than after the remainder of the sessions. These results were interpreted as adaptation to the simulator.

Reports and manuals that provide guidelines for the detection and treatment of SS acknowledge adaptation as the best current solution to the problem of simulator-induced discomfort (e.g., Kennedy et al., 1987; Lilienthal et al., 1987; NTSC, 1988). As with MS, almost all participants eventually adapt to a simulated motion environment. Guidelines often describe procedures to employ during simulator-based flight training to encourage a rapid and reasonably comfortable adaptation period. For example:

> Adaptation of the individual is one of the strongest and most potent fixes for simulator sickness... Do not schedule simulator hops for greater than two hours for any reason. (Kennedy et al., 1987, pp. 12, 17)

> Persons new to the simulator, and particularly persons with extensive flight time, are at most risk... Decrease the field of view during nauseogenic hops (e.g., initial hops)... Go on instruments. (Lilienthal et al., 1987, pp. 277, 279)

> Brief simulator flights (short hops with gentle maneuvers) separated by one-day intervals will facilitate adaptation to simulator motion and help prevent sickness, especially during the early stages of simulator training for novices and for experienced pilots with little simulator training... Do not slew while the visual scene is turned on... If all else fails, turn off the motion base or the visual scene and conduct instrument training. (NTSC, 1988, pp. 6-7)

Susceptibility

SS is not only polysymptomatic; it is polygenic (Kennedy & Fowlkes, 1992; Kennedy & Frank, 1985). Kennedy & Fowlkes listed 13 factors that are implicated in causing SS. These factors were subdivided into three categories: individual variables, simulator variables, and task variables. In an exhaustive review, Kolasinski (1995) described 40 factors that are associated with SS—also categorized as individual, simulator, and task variables. Pausch et al. (1992) reviewed several factors that evoke SS, with special emphasis given to simulator design issues.

Gender. As with MS (e.g., Reason & Brand, 1975), reviews of SS reported that females are more susceptible than males (e.g., Biocca, 1992; Kennedy & Frank, 1985; Kolasinski, 1995; Pausch et al., 1992). The precise reason for this is unknown. Reviewers have cited at least three possible explanations: hormonal differences, FOV differences, and biased self-report data. The hormonal hypothesis is that females are more susceptible to SS during a portion of their menstrual cycle. This hypothesis is not without its doubters (e.g., Biocca; Pausch et al.). More likely, some think, is the fact that females have a larger effective FOV, and larger FOV is associated with greater SS (e.g., Biocca; Kennedy & Frank; Pausch et al.). Finally, those data

upon which gender differences are based are self-reports. Males, it is suggested, may be more likely to under-report the severity of their discomfort (e.g., Biocca; Kolasinski).

However explained, reports of gender differences in SS continue to emerge. Hein (1993) reported the results of 22 separate studies, involving 469 participants, over the course of 6 years. All studies took place in a fixed-base, automobile-driving simulator. Hein stated that gender differences in susceptibility to SS were among the most consistent results. "At all ages, female drivers are more susceptible than male drivers" (Hein, p. 610).

Age.

> Walt Disney World's "Mission: Space" thrill ride left some older riders gulping, "Houston, we have a problem." In the past eight months, six people over 55 have been taken to the hospital for chest pain and nausea after going on the $100 million ride… It is the most hospital visits for a single ride since Florida's major theme parks agreed in 2001 to report any serious injuries to the state… Last December, Disney began placing barf bags in the ride… (Schneider, 2004, p. B2)

Reviewers have reported that susceptibility to SS varies with age in the same way that MS varies with age (e.g., Biocca, 1992; Kennedy & Frank, 1985; Kolasinski, 1995; Pausch et al., 1992; Young, 2003). That is, below age 2 infants are generally immune. Susceptibility is at its highest level between ages 2 and about 12. There is a pronounced decline between ages 12 and 21. This decline continues, though more slowly, through adulthood until about age 50, after which SS is very rare. These claims are not based on simulator research but on the self-report data reviewed by Reason and Brand (1975) for MS in vehicles.

Perhaps the reason reviewers report conclusions based on decades-old self-report surveys of MS symptoms, is because so little research has been performed examining the effect of age on susceptibility to SS. Very few researchers have attempted to investigate the relationship between age and SS more directly. Braithwaite and Braithwaite (1990) administered questionnaires to 230 pilots attending training in a simulator for the Lynx attack helicopter. All were males. Age ranged from 23 to 42 years with a mean age of 32. There was no relationship found between age and reported SS.

Warner et al. (1993) assessed SS in two wide-FOV F-16 flight simulators. Twenty-four male pilots participated in total. Sixteen were active-duty military pilots of mean age 28.6 years ("younger group"). Eight were older active-duty military pilots and former military pilots of mean age 52.1 years ("older group"). The task was a challenging 50-minute flight through a long, narrow, twisting canyon in each of the two simulators, in counter-balanced order, two weeks apart. One pilot from the younger group (1/16 = 6.25%) terminated a session prematurely due to severe SS. Three pilots from the older group (3/8 = 37.5%) terminated a session prematurely due to severe SS. The discomfort ratings collected from pilots who terminated prematurely were significantly higher than those from pilots who completed the flight. Among those pilots who completed the flight, there was no significant difference in discomfort ratings

between the younger and older groups. Among those pilots who completed the flight, there was also no significant difference in postural equilibrium (SOLEC, WOFEC) between the groups.

Hein (1993) reported the results of 22 separate studies, involving 469 participants of both genders and a wide range of ages, over the course of 6 years. All studies took place in a fixed-base, automobile-driving simulator. Hein stated that age differences in susceptibility to SS were among the most consistent results. "Younger, male drivers adapt easily. Older drivers and women are severely susceptible to simulator sickness" (Hein, p. 611).

Age and experience. Among those who have been involved in the simulator-based training of large numbers of aviators, it is common knowledge that older participants are more susceptible to SS. Yet researchers investigating SS rarely even aggregate their data by age. Given the importance of age in both behavioral science and medical science research, this appears to be a glaring omission. Then, to confuse matters further, reviewers of the SS literature continue to repeat the conclusions published by Reason and Brand (1975) for MS in vehicles that sickness decreases with age and eventually almost disappears. Why is this so?

This is because researchers are convinced that the demographic variable that influences aviator SS is experience as measured in flight hrs, not chronological age. Data are frequently aggregated by the flight hrs of the participants. Researchers reviewing the literature discuss the impact of aircraft flight experience on SS. This view is also entirely consistent with the sensory conflict theory, where experience in a particular motion environment is central to the explanation.

However, among aviators, age (in years) and experience (in flight hrs) are strongly linked. Magee et al. (1988) reported a statistically significant correlation between age and flight hrs ($r = 0.67$). This is because "As is common in most professions, piloting experience tends to accumulate with age" (Tsang, 2003, p. 525). Thus, disentangling age from experience is a knotty problem when examining SS among aviators (see Tsang).

It would not, in principle, be such a difficult problem to assess the effect of age upon SS if non-aviators were used as research participants. The present author predicts that among adult non-aviators, SS will increase with age rather than decrease. The chief methodological problems to be solved in order to perform this research would be practical ones. First, gaining access to a sufficiently large sample of non-aviators of a wide range of ages. Second, gaining access to a flight simulator for a period of time sufficient to collect the requisite large amount of data.

Experience. It is universally understood within this research community that the more experienced aviators are more susceptible to SS than novices. For example, this understanding has been acknowledged in at least 12 reviews covering the period from 1984 to 2003 (Benson, 1988; Crowley & Gower, 1988; Kennedy et al., 1987; Kennedy & Fowlkes, 1992; Kennedy & Frank, 1985; Kolasinski, 1995; Lilienthal et al., 1987; McCauley, 1984; Mooij, 1988; Pausch et al., 1992; Wright, 1995; Young, 2003). In addition, some empirical evidence of this relationship has already been described earlier in the reports by Crowley (1987), McGuinness et al. (1981), and Miller and Goodson (1958, 1960).

More recent evidence has supported this relationship—although not consistently so. Braithwaite and Braithwaite (1990) found a statistically significant positive correlation between experience as measured in flight hrs and SS among pilots training in a simulator for the Lynx helicopter. That is, pilots with a greater number of flight hrs reported greater SS. Gower and Fowlkes (1989b) assessed SS among 87 Army aviators training in a UH-60 helicopter simulator. They found a significant positive correlation between flight hrs and SSQ scores. Gower et al. (1989) collected data from 57 aviators with flight experience ranging from 450 to 7,000 flight hrs. The pilots were taking currency training in a simulator for the CH-47 cargo helicopter. The authors found no correlation between flight hrs and SSQ scores. Gower et al. (1987) assessed SS among 127 Apache aviators with flight experience ranging from 150 to 8,400 flight hrs. All pilots were training in the AH-64 CMS. Again, the authors found no significant correlation between flight hrs and reported SS symptoms.

Magee et al. (1988) assessed SS among a group of 42 male C-130 pilots and flight engineers operating a CAE C-130 simulator. Twenty-six participants ("experienced group") had flight hrs ranging from 845 to 10,000 (median 3,166). Sixteen participants ("novice group") had flight hrs ranging from 50 to 4,340 (median 1,465). There was no significant difference between the two groups in measured SS, either immediately after the simulator session or later. Also, a partial correlation of flight hrs against measured SS, with age held constant, showed a small (0.03) and statistically nonsignificant result.

Silverman and Slaughter (1995) collected data from 13 aviators as part of an operational test of a MH-60G PAVE Hawk simulator. The participants' total flight experience ranged from 350 to 15,327 hrs. The authors reported that there was no statistically significant correlation between reported SS and either total flight hrs or flight hrs for the specific MH-60G helicopter. Uliano et al. (1986) assessed SS among 25 male helicopter pilots. Their flight experience ranged from 360 to 2,860 hrs (mean 1,071). All participants operated the VTOL simulator, which represented the SH-60B Seahawk helicopter. Aviators with fewer than 900 flight hrs experience reported significantly less SS on all measures than those with 900 or more flight hrs.

Lerman et al. (1993) collected data from 59 male armor Soldiers operating a tank driver trainer. The authors found no significant correlation between amount of prior tank driving experience and SS symptoms.

Sensory conflict theory states that SS is caused when there is a difference between the current pattern of sensory information and what is expected on the basis of past experience. Thus, this theory predicts that the more flight experience an aviator has acquired, the greater will be the disparity between his or her neural store and the pattern presented by the flight simulator—since a simulator cannot perfectly simulate flight—and the more SS will be reported. This is the explanation given when statistically significant differences are found between highly experienced aviators and novices or students.

Prior history of motion sickness. Generally speaking, in the behavioral sciences past behavior is the best predictor of future behavior. It follows that people who have a history of prior episodes of MS or SS will be more likely to experience SS in future simulator-based training. Two reviewers reported that there is empirical evidence in support of this

generalization (Kennedy et al., 1987; Wright, 1995). Kennedy, Fowlkes, Berbaum, and Lilienthal (1992) discussed using the Motion History Questionnaire (MHQ) to predict sickness scores in a simulator.

Braithwaite and Braithwaite (1990) reported that among their sample of helicopter pilots training in a Lynx simulator, there was a significant positive correlation between self-reported prior history of MS and SS. That is, those with a history of MS were more likely to experience SS in the helicopter simulator. Gower and Fowlkes (1989a) reported a significant positive correlation between past history of MS as reported on the MHQ and reported SS while training in the Cobra FWS. Gower and Fowlkes (1989b) also reported a significant positive correlation between reported history of MS and SS among helicopter pilots training in a UH-60 simulator. Gower et al. (1989) found this same statistically significant relationship between MHQ scores and early-version SSQ scores for aviators training in a simulator for the CH-47 cargo helicopter.

Gower et al. (1987) collected data from 127 rated aviators training in the AH-64 CMS. They found a significant positive correlation between prior history as reported on the MHQ and SS as reported on a MS questionnaire. Kennedy et al. (1988) reported the results of surveying 1,186 pilots training in 10 Navy simulators. Five of the simulators were FW and five were RW. They reported a small, but statistically significant, positive correlation between MHQ scores and SS symptoms. Warner et al. (1993) did not find any significant relationship between MHQ scores and SS symptoms for 24 pilots operating two F-16 simulators. Twenty-four participants, however, is usually too small a sample size for a meaningful study of the correlates of SS (Kennedy & Fowlkes, 1992).

Lampton et al. (1995) reported this same relationship for a sample of 115 male trainees operating an M-1 tank driver simulator. Trainees were asked, "Have you ever experienced motion sickness (such as in a car or bus, on a plane or train, on an amusement park ride, seasickness, etc.)?" Twenty-two percent responded in the affirmative. Those answering yes were significantly more likely to score higher on the SSQ. Lerman et al. (1993) assessed 59 male armor Soldiers during tank driver training in a tank simulator. The authors reported a significant positive relationship between prior history as measured by the MSQ and SS as measured by a MS questionnaire.

To summarize, two reviewers as well as eight of nine research studies document that a prior history of MS is positively correlated with SS. Past behavior is the best single predictor of future behavior.

Miscellaneous: illness, drugs, sleep, fatigue. There are several health-related conditions that are known to influence susceptibility to SS. As with MS, there is the pathology of an absent or nonfunctional vestibular system. Persons with this pathology ("labyrinthine defectives") are incapable of experiencing either MS (e.g., Benson, 1978; Reason & Brand, 1975) or SS (e.g., Kennedy & Frank, 1985; Pausch et al., 1992).

It is widely understood among the research community that individuals should not participate in simulator-based training unless they are in their usual state of health and fitness. Individuals in ill health are more susceptible to SS (e.g., Kennedy et al., 1987; Kennedy &

Fowlkes, 1992; Kolasinski, 1995; McCauley, 1984; NTSC, 1988; Pausch et al., 1992; Wright, 1995). Symptoms that make individuals more vulnerable include hangover, flu, respiratory illness, head cold, ear infection, ear blockage, and upset stomach. Individuals exhibiting these symptoms should not participate in simulator-based training or simulator-based research (Kennedy, Lane, et al., 1993). Similarly, it is widely known that certain medications, drugs, and alcohol can increase an aviator's susceptibility to SS (e.g., Biocca, 1992; Kennedy et al., 1987; Kennedy & Fowlkes; NTSC; Young, 2003).

Reviewers have stated that fatigue and sleep loss also predispose an individual to SS (e.g., Kennedy et al., 1987; NTSC, 1988; Pausch et al., 1992; Wright, 1995). Gower and colleagues (Gower & Fowlkes, 1989a; Gower & Fowlkes, 1989b; Gower et al., 1987) have repeatedly reported a significant inverse relationship between the numbers of hrs slept the previous night and SS as measured on an early version of the SSQ. That is, the fewer the hrs slept, the greater the SSQ score. Gower et al. (1989) reported a significant negative biserial correlation between self-reported "enough sleep" (yes or no) and SS. Those aviators who reported that they had not had enough sleep last night, scored higher on the SSQ. This relationship between fatigue/sleep and SS is no trivial result. In military aviation training it is common for aviators to be less than fully rested during initial, advanced, or recurrent training.

Simulator variables. There are several simulator factors that have been implicated as causal in SS. Arguably the two most thorough reviews of these factors can be found in Kolasinski (1995) and Pausch et al. (1992). The review presented below is not an exhaustive listing of known simulator variables.

Wide FOV visual displays have long been associated with increased susceptibility to SS (Hein, 1993; Kennedy & Fowlkes, 1992; Kolasinski, 1995; McCauley, 1984; Pausch et al., 1992). This is because with a wider FOV there is a greater perception of visual flow or vection. Another visual factor with a long history of association with SS is known as off-axis viewing, design eye point, or viewing region (Kennedy & Fowlkes; Kolasinski; McCauley). Every visual flight simulator has a design eye point. This is the location within the cockpit where the visual display can be viewed best and where the pilot should keep his or her head positioned. Moving one's head away from the design eye point, or optimal viewing region—by slouching or leaning forward, for example—will not only guarantee a poorer visual image, but will increase one's likelihood of experiencing discomfort. Perhaps the oldest visual factor known to evoke SS (e.g., Miller & Goodson, 1958, 1960) is optical distortion caused by misaligned or poorly calibrated optics (Ebenholtz, 1992; Kennedy & Fowlkes; Kolasinski; Lerman et al., 1993; McCauley). Finally, the general issue of cue asynchrony (visual delay, transport delay, asynchronous visual and motion systems) has been investigated as a source of SS, but with equivocal results (Hein; Kolasinski; McCauley; Pausch et al; Uliano et al., 1986).

Task variables. Not surprisingly, what the participant does while in the simulator, and what is done to him or her, can have a marked impact upon susceptibility to SS. These task factors were particularly well presented in the reviews by Kolasinski (1995) and McCauley (1984). The review of task variables presented below is not exhaustive.

First in importance is session duration (Gower & Fowlkes, 1989a; Gower et al., 1987; Kennedy & Fowlkes, 1992; Kolasinski, 1995; McCauley, 1984; Wright, 1995). The longer the period of time spent operating the simulator, the greater the likelihood of significant discomfort. Another important factor is use, by the instructor, of the freeze/reset command (Gower et al., 1989; Gower et al., 1987; Kennedy & Fowlkes; Kolasinski; McCauley; Wright). The more often the instructor freezes the pilot in mid-flight—to prevent a crash or provide instruction, for example—the more likely the pilot will experience SS. Other unusual or unnatural maneuvers, such as moving forward/backward in time or flying backwards, are also associated with increased risk of discomfort (Kolasinski).

Maneuver intensity (aggressive, dynamic, or violent maneuvering) has been implicated in SS, both in flight simulators (McCauley, 1984; Wright, 1995) and automobile simulators (Hein, 1993). Also, the height above terrain at which pilots fly has been shown to vary inversely with discomfort level (Gower et al., 1989; Kennedy & Fowlkes, 1992; Kolasinski, 1995; Wright). Flying close to the ground (nap of the earth) causes more SS than flying at altitude. This is usually explained in terms of greater perception of visual flow, caused by greater visual detail or density, at lower height above terrain. Degree of control has been associated with increased susceptibility to SS (Kolasinski; Pausch et al., 1992; Riccio & Stoffregen, 1991). The pilot in control of the simulator tends to report less discomfort than a passive passenger. Finally, head movements increase susceptibility to SS (Kennedy & Fowlkes; Kolasinski; McCauley; Riccio & Stoffregen). This last point has long been a part of trainee lore. Participants, who find themselves vulnerable to SS, quickly learn to keep their heads stationary.

Simulator Sickness, Performance, and Training

Performance. Does SS harm the flight performance of experienced aviators while in the simulator? Does exposure to a simulator temporarily harm the cognitive, perceptual, or psychomotor performance of the participants? These are not subjects that have received a large amount of research attention.

Silverman and Slaughter (1995) stated that 67 percent of the helicopter pilots in their experiment reported modifying their flight control inputs at some point during the simulator sessions to alleviate the symptoms of SS. Pilots reported that they "slowed control inputs" or "transferred controls" or "closed my eyes during rapid aircraft movements" (p. 16). Uliano et al. (1986) had 25 experienced male helicopter pilots perform a series of tasks in the VTOL simulator. All pilots were to perform both an air taxi task and a slalom task according to prescribed standards. Performance in executing these tasks to standards was measured in three spatial dimensions (x, y, z). The authors found that there was a statistically significant negative correlation between the amount of SS reported and performance on the air taxi task. Specifically, the sicker were the aviators, the greater the percentage of time they flew out of tolerance in x, y, or z. The authors did not find a statistically significant relationship for the slalom task. Warner et al. (1993) assessed 24 pilots flying two F-16 flight simulators through a challenging 50-minute course. They collected 18 objective measures of piloting performance (e.g., airspeed limits, height above ground level, etc.). These they correlated with SSQ scores. The authors found no consistent relationship between SS scores and piloting performance.

As part of their larger survey of Navy simulators Kennedy et al. (1988) performed tests of cognitive, perceptual, and psychomotor capabilities. Three tests (Pattern Comparison, Grammatical Reasoning, Speed of Tapping) were administered both before and immediately after simulator exposure.

> Pre- versus post-performance changes were studied in only six different simulators. In no simulator were group performances poorer after exposure, and indeed, most changes showed learning effects from the first (pre) to the second (post) session. Based on interpolations from other experiments on nonpilot subjects, these changes appear within the range of improvements due to practice which are to be expected over two sessions. (Kennedy et al., 1988, p. 5)

Kennedy, Fowlkes, et al. (1993) measured performance on three tasks (Pattern Comparison, Grammatical Reasoning, Finger Tapping) both before and after simulator exposure for 411 aviators engaged in simulator-based training. These data were compared to that from a control group of 16 aviators who were not exposed to a simulator between the first (pre) and second (post) test. Both groups showed improvement (a practice effect) from the pre-test to the post-test for all three tasks. However, the improvement shown by the control group was greater than that shown by the simulator-exposed group. This was a small, but statistically significant, difference. In other words, the simulator exposure attenuated the size of the practice effect for the simulator group. Uliano et al. (1986) tested 25 experienced male helicopter pilots on a grammatical reasoning task both before and after a 40-minute simulator flight. They reported that there was no statistically significant effect of the simulator flight on performance of the grammatical reasoning task.

Based on the limited evidence that exists, it appears that simulator exposure has little or no effect on the cognitive, perceptual, or psychomotor abilities of aviators.

Training. With the exception of simulator-based rides at theme parks, simulators are used for training important and often dangerous skills—such as flying a helicopter or driving a tank. Does SS harm this training? For anyone who has experienced simulator-induced discomfort, it certainly appears reasonable to suggest that SS may interfere with training. But does it? What is the evidence?

The fear that SS would limit the usefulness of simulators for flight training has been in existence for decades (Miller & Goodson, 1958, 1960). In fact, Miller and Goodson reported that use of the device they evaluated was discontinued. Recall also that two of McCauley's four points concerned this issue (McCauley, 1984). He warned of compromised training and decreased simulator use caused by SS.

When researchers review the literature of SS, the possibility of compromised training and/or decreased simulator use is a common feature. In at least 15 published reports between 1986 and 1997 researchers have mentioned this potential problem of simulator-based training (Casali & Frank, 1988; Crowley, 1987; Crowley & Gower, 1988; Kennedy et al., 1988; Kennedy

et al., 1987; Kennedy, Fowlkes, et al., 1992; Kennedy, Lane, et al., 1992; Kolasinski, 1995, 1997; Lampton et al., 1995; Lilienthal et al., 1987; Mooij, 1988; Pausch et al., 1992; Wright, 1995; Uliano et al., 1986).

> Although studies indicate that sickness can occur, little—if any—research has investigated whether such sickness has an impact on training effectiveness. (Kolasinski, 1997, p. 151)

Given the primacy of this issue since 1958, it is remarkable how little empirical evidence there is on the subject. Chappelow (1988) administered questionnaires to 271 Royal Air Force pilots training in either of two air combat simulators. Respondents who had reported sickness symptoms were asked to assess the effect of the experience on their willingness to use the simulator in the future. A total of 214 pilots answered this question. Four percent reported that the experience decreased their willingness to use the simulator again. Sixty-eight percent responded that it had no influence. Twenty-eight percent stated that the experience increased their willingness to use the simulator again, because they said it provided good training and was fun to operate.

Gower and Fowlkes (1989a) assessed the effect of SS on training by asking their sample of AH-1 pilots whether simulator-induced discomfort hampers training. They found two related results. First, there was a statistically significant positive correlation between SSQ scores and agreement with the statement that "discomfort hampers training." That is, the aviators who reported the most SS were more likely to agree that discomfort harms training. Second, only eight percent of their sample agreed, "discomfort hampers training." Four percent were neutral on the question. Eighty-eight percent disagreed with the statement. It should be noted that these results were the self-reported opinions of Army aviators. No grades, test results, set-backs, or other performance measures were presented to show in an objective fashion that, in fact, those participants experiencing more discomfort learned less than their non-sick counterparts.

Gower and Fowlkes (1989b) asked the same questions of their sample of UH-60 pilots and found the same pattern of results. First, there was a statistically significant positive correlation between SSQ scores and agreement with the statement that "discomfort hampers training." Second, this was the opinion of a small minority of their sample. Only one person (1%) of the 86 who answered this question agreed that discomfort disrupts training. Fifteen percent were neutral. Eighty-four percent disagreed with the statement. Again, no data on performance during training were collected that would bear on the issue of SS and amount learned.

Gower et al. (1989) found the same pattern of results with their sample of helicopter pilots training in the CH-47 flight simulator. There was a significant positive correlation between SSQ scores and agreement with the statement that "discomfort hampers training." Again, only one person (1.5%) agreed with the statement. Two people were neutral (2.9%). Of the total of 68 responses to this question, 65 (95.6%) disagreed with the statement. Finally, as before, no performance data were presented as to SS and amount learned during training.

The results of these four studies are clear. The majority of the aviators surveyed stated that the discomfort-producing potential of the devices did not detract from the training provided. However, a small minority of aviators—those experiencing the most sickness—held the opposite opinion. Given the centrality of this issue for simulator-based training, more research should be undertaken. Measures of performance in learning the required program of instruction should be correlated with measures of SS. In agreement with the quote from Kolasinski (1997) above, the present author knows of no published research devoted to this question.

Treatment

As with MS in general, the surest treatment for SS is simple adaptation. Nearly everyone will adapt to a particular simulator eventually. To aid adaptation to a new simulator, aviators should begin with brief simulator hops, flying gentle maneuvers, with subsequent hops separated by one- to five-day intervals (Kennedy, Lane, et al., 1993; NTSC, 1988). In this context, "brief" means less than one hr, with breaks as needed. The maximum duration of any simulator session should never exceed two hrs. Several other guidelines exist and will be described later.

For those pilots who cannot adapt to a simulator, "...anti-motion sickness medication may be considered for the simulator period" (Crowley, 1987, p. 357). Drugs previously used to control the symptoms of MS, such as hyoscine hydrobromide and dimenhydrinate (Dramamine), have also proven effective for relief of SS (Benson, 1978; Reason & Brand, 1975; Regan & Ramsey, 1996). In the world of flight training, it is no secret that some aviators with a history of discomfort self-medicate with MS drugs prior to a simulator session. However, no drug can reduce the occurrence of SS for everyone. Further, every drug has side effects. For example, scopolamine administered as a treatment for SS is known to have side effects that could negatively affect learning (Crowley, 1990). An aviator with severe, intractable SS should visit his or her flight surgeon.

Theory

SS is a form of MS. The two major theories that exist to explain MS are also used to explain SS. By far the more common is the sensory conflict theory (Benson, 1978; Reason, 1970, 1978; Reason & Brand, 1975). Virtually all research reports mention the sensory conflict theory by one of its names. Most authors employ it in the explication of their results. Early examples of how this theory has been applied to SS can be found in Kennedy and Frank (1985), McCauley (1984), and Reason and Brand. The major competitor is the postural instability theory (Riccio & Stoffregen, 1991; Stoffregen, Hettinger, Haas, Roe, & Smart, 2000; Stoffregen & Smart, 1998). For a more detailed description of these theories than is presented here, the reader is encouraged to see Johnson (2005).

Sensory conflict theory. The sensory conflict (SC) theory states that sensory inputs from the eyes, semicircular canals, otoliths, proprioceptors, and somatosensors are provided in parallel both to a neural store of past sensory patterns of spatial movement and to a comparator unit. This comparator unit compares the present pattern of motion information with that pattern expected based on prior motion history and stored in the neural store. A mismatch between the

current pattern and the stored pattern generates a mismatch signal. This mismatch signal initiates both SS and the process of adaptation.

According to the SC theory, when an aviator is operating a new simulator the pattern of motion information presented by the senses is at variance with past experience in the flight environment. This conflict between the current sensory pattern and that pattern expected based upon past experience causes SS. That is, there is a conflict between the current novel motion environment and past experience. However, with continued sessions operating the device the relative mismatch between current pattern and stored patterns decreases until one has adapted. Flight simulators attempt to simulate flight—that is, to trick the human perceptual system. However, no device can perfectly simulate all the physical forces of flight. It is this inability to simulate flight perfectly that causes SS in experienced aviators.

However, one need not be an aviator to know the discomfort of SS. Anyone with a normal vestibular system is susceptible to SS when operating a novel motion simulator. The key concept is the mismatch between the novel motion environment (the current pattern of sensory stimulation in the simulator) and prior motion history (the patterns of sensory stimulation resident in the neural store). The SC theory explains SS in exactly the same fashion it explains MS—only the motion environment has changed.

Postural instability theory. The postural instability (PI) theory notes that sickness-producing situations are characterized by their unfamiliarity to the participant. This unfamiliarity sometimes leads to an inability of the participant to maintain postural control. It is this postural instability that causes the discomfort—until the participant adapts. That is, a prolonged exposure to a novel motion environment causes postural instability that precedes and causes the sickness.

PI theory states that there are individual differences in postural control. Evidence in support of these individual differences in postural control and their relationship to reported MS has been provided by Owen, Leadbetter, and Yardley (1998). Further, an imposed motion presented by a simulator can induce postural instability. The interaction of the body's natural oscillation with the imposed oscillation created by the simulator leads to a form of wave interference effect that causes postural instability. This instability is the proximate cause of SS. Experimental evidence in support of this theory—from participants exposed to simulated motion—has been reported (Smart, Stoffregen, & Bardy, 2002; Stoffregen et al., 2000; Stoffregen & Smart, 1998). The PI theory explains SS in exactly the same fashion it explains MS—only the nature of the novel motion environment has changed.

SS, age, and theory. The SC theory and the PI theory make different predictions in some instances (cf., Johnson, 2005). One issue on which these two competing theories make opposite predictions concerns the effect of age on susceptibility to SS.

The SC theory states that MS in all its forms must decline with age after about age 12 (Benson, 1978; Reason & Brand, 1975). The reasons for this are that life experiences provide the neural store with a wealth of prior sensorimotor patterns of motion memories and also that receptivity (the strength of the mismatch) declines with age. The SC theory predicts that SS will

decline with age. However when research shows that SS increases with age, these results are dismissed as being the product of a confounding with flight experience. Age and flight experience are strongly correlated among pilots (Magee et al., 1988; Tsang, 2003). The SC theory predicts that with increasing flight hrs the relative mismatch between the sensorimotor pattern of aircraft flight and that of simulator "flight" will be greater and will, therefore, engender more SS. However, this interpretation only exists because the overwhelming majority of simulator research has taken place in the world of aviator training—a world where older aviators are also more experienced aviators. The SC theory would predict that a large sample of adult non-aviators of widely different ages would show *decreasing* SS with increasing age.

The PI theory would make exactly the opposite prediction. According to this theory, SS is caused by postural instability. Postural stability among adults is known to decline with increasing age—markedly so for the elderly (see below). Therefore, PI theory would predict that a large sample of adult non-aviators of widely different ages would show *increasing* SS with increasing age. Further, within any age cohort this theory predicts that greater instability will be associated with greater SS. So this theory not only makes a general prediction concerning age, but also makes a prediction concerning specific aged adults.

Postural instability and age. Age brings physiological changes. Among these changes is increased postural instability. All human sensory systems decline with age (Kane, Ouslander, & Abrass, 1994; Newman & Newman, 1987). Lord (2003) listed several documented age-related declines in visual capabilities, including acuity, peripheral vision, contrast sensitivity, and stereopsis (two-eye depth perception). There are age-related changes in neuromuscular function, gait, and postural reflexes (Kane et al., 1994). The maintenance of postural stability involves the interaction of several bodily systems, but the contribution of the vestibular system is primary. Age dependent vestibular degeneration is an established fact for human beings as well as other mammals (Lyon, 2003, October).

> Increasing age is associated with diminished proprioceptive input, slower righting reflexes, diminished strength of muscles important in maintaining posture, and increased postural sway. (Kane et al., 1994, p. 199)

Several researchers have measured postural stability as a function of age in healthy, non-institutionalized populations (Choy, Brauer, & Nitz, 2003; Gill et al., 2001; Matheson, Darlington, & Smith, 1999). Postural stability was defined as postural sway in these experiments and was measured in different ways. Matheson et al. (1999) measured postural stability in degrees of sway from the center of pressure in a sample of 76 subjects who ranged in age from 18 to 60+ years. The two major results were that 1) with an increase in age, there was a significant increase in measured sway, and 2) with an increase in the difficulty of the testing conditions (e.g., eyes closed, standing on a soft surface), there was a significant increase in sway.

> …there is a significant decline in postural control with increasing age, as indicated by increased postural sway, and this deficit becomes greater as the conditions of testing become more difficult… (Matheson et al., 1999, p. 262)

Gill et al. (2001) recorded five measures of trunk sway in a sample of 147 males and females, who ranged in age from 15 to 75 years, on a battery of seven stance tasks, two stance-related tasks, and five gait tasks. The results showed significantly more sway for the elderly subjects on the stance and stance-related tasks. In addition, the elderly required significantly more time to complete all the gait tasks.

Choy et al. (2003) measured velocity of postural sway (m/s) on eight balance and stance tasks for a sample of 453 normal women aged 20 to 80 years. They found that with increasing age there was a significant increase in postural instability both on balance tasks and stance tasks. There was more sway with eyes closed, and more sway on a soft surface than on a firm one.

> The decreased ability to balance on a soft surface when vision is removed supports the view that detrimental changes may have occurred in the other sensory systems involved in postural stability (vestibular and/or somatosensory systems) by the 50s… It is clear that changes in postural stability are well established by age 60 when vision is not available… (Choy et al., 2003, pp. 528-529)

Lord (2003) noted that postural sway among older adults was influenced by several visual factors including acuity, peripheral vision, contrast sensitivity, and stereopsis. As visual capability in these areas decreased, postural sway significantly increased. As noted above, all these visual factors decline with increasing age. Thus, postural instability increases with increasing age with eyes open or closed, based on sensory deficits of the vestibular system, proprioceptors, and vision, along with degradation in motor control, muscle strength, and gait.

Aviators are not immune from age-related changes. A study by Olive (as cited in McGuinness et al., 1981) correlated physical and medical data from 1,000 Naval aviators over a twenty-year period. Results indicated that susceptibility to vertigo and disorientation increased with age.

These age-dependent decrements in sensorimotor function are not mere laboratory curiosities. As people age they are increasingly likely to fall, and these falls are increasingly likely to result in serious injury or death (Kane, et al., 1994). Falls are the leading cause of injury-related deaths for the elderly (Baker & Harvey, 1985). Among women, fall injuries begin to increase significantly at age 40 (Baker & Harvey).

> In 2004, the most recent year statistics are available, almost 15,000 people 65 and older died from falls and about 1.9 million were treated for injuries in emergency rooms, said Judy Stevens, an epidemiologist with the Centers for Disease Control and Prevention… 'I think the magnitude of the problem is something that people don't recognize,' Stevens said. 'It really is a serious issue for older adults.' (Stengle, 2007, p. 6A)

> More than one third of persons 65 years of age or older fall each year, and in half of such cases the falls are recurrent… Approximately 1 in 10 falls results in a serious injury, such as hip fracture… Falls account for

> approximately 10 percent of visits to the emergency department and 6 percent of urgent hospitalizations among elderly persons… (Tinetti, 2003, p. 42)

According to Tinetti, Speechley, and Ginter (1988), 30 percent of persons over age 65 in the community (i.e., non-institutionalized) fall each year; while 40 percent of persons over age 80 in the community fall each year. Falls are mentioned as a contributing factor in 40 percent of admissions to nursing homes (Tinetti et al.). In a prospective study, Tinetti et al. evaluated 336 non-institutionalized participants in the Yale Health and Aging Project who were at least 75 years of age (M = 78.3). After a thorough medical, sensorimotor, and demographic evaluation, this sample was followed bi-monthly for 12 months. Thirty-two percent of this sample fell at least once during the follow-up period. Tests of balance and gait at the evaluation were significantly correlated with falls during the follow-up period.

Campbell, Borrie, and Spears (1989) used the prospective study method to follow 761 participants, all at least 70 years of age, for one year after an initial assessment. All falls were documented on forms as well as monthly telephone calls. Thirty-five percent of this sample fell at least once during the follow-up year (40% of females fell, 28% of males fell). There was a significant positive correlation between age of participant and reported falls. For men, there was a significant positive correlation between body sway at initial assessment and reported falls during the yearly follow-up.

Buatois, Gueguen, Gauchard, Benetos, and Perrin (2006) also used the prospective study method to investigate several posturographic assessment techniques and their relationship to falls among elderly persons. Two hundred and six healthy, non-institutionalized participants with no known balance pathologies were first given a battery of several posturographic tests and then followed for 16 months. After this period their data were aggregated into three groups: Non-Fallers, who had zero falls in the follow-up period; Single-Fallers, one fall; and Multi-Fallers, two or more falls. The Multi-Fallers were different from the other two groups at initial assessment in only two ways. First, the Multi-Fallers showed significantly more body sway on the Sensory Organization Test, and two, they showed no postural adaptation during repeated trials of this test, unlike participants in the other groups.

The purpose of this section has been to establish for the reader that postural instability has been studied extensively, in several contexts, and using several different methods. A consistent result has been that with increasing age there is an increase in instability. Therefore, if postural instability is the proximate cause of SS, as adherents of the PI theory claim, then a cross-sectional study of SS as a function of age should result in a statistically significant positive correlation between age and measured SS. The SC theory makes the opposite prediction.

Guidelines for Reducing Simulator Sickness and Risks from Aftereffects

Several authors have taken the time to publish guidelines in an effort to reduce the rate of SS among trainee populations (Braithwaite & Braithwaite, 1990; Crowley & Gower, 1988; Johnson, 2005; Kennedy et al., 1987; Kolasinski, 1995; Lilienthal et al., 1987; McCauley, 1984; NTSC, 1988; Wright, 1995). Arguably the most thorough set of guidelines are those by

Kennedy et al. and Wright. These authors not only provide guidelines, but also explain the reasons for the guidelines and the evidence supporting them. If the reader does not have time for a detailed presentation, the best and most entertaining single source is the field manual published by the Naval Training Systems Center (NTSC).

The author lists some suggestions. This is by no means an exhaustive listing.

General rules.

- Simulator flights should not be scheduled on the same day as aircraft flights.
- Arrive for simulator training in your usual state of health and fitness.
    - Avoid fatigue or sleep loss, hangover, upset stomach, head colds, ear infections, ear blockages, upper respiratory illness, medications, and alcohol.
    - If you have been sick recently and are not fully recovered, reschedule your simulator training.
- Persons who are new to the simulator, or who have not operated it in months, are at risk.
- Do not schedule simulator sessions for greater than two hours for any reason.
    - Use breaks, time-outs extensively.
    - The more nauseogenic the session, the shorter the session should be.
        - Aggressive, violent maneuvers, near ground level, are more nauseogenic than high, straight-and-level flight.
- Adaptation is one of the most potent fixes for SS.
    - In order to optimize adaptation, there should be a minimum of one day between simulator sessions, and a maximum of seven days.
    - Begin with short sessions, using non-nauseogenic maneuvers.
    - Minimize rapid gain and loss in altitude; minimize abrupt or continued roll; minimize porpoising.
    - Fly the most provocative tasks at the end of the session.
- Minimize head movement, particularly when new or dynamic maneuvers are being trained.
- Tell your instructor if you are experiencing discomfort.
- The instructor should avoid, or at least minimize, use of the freeze command.
    - Have the pilot close his or her eyes before using the freeze command.
    - Have the pilot close his or her eyes before resetting the simulator to another location. Or, turn off visual display before reset.
- The instructor should turn off visual display and turn on cabin lights before asking the pilot to exit the simulator.
- The instructor should decrease the field of view (turn off side displays) during early sessions, nauseogenic maneuvers, or if the pilot shows any symptoms of discomfort.
    - Or, go on instruments at the first sign of discomfort.
- Avoid high-risk activities for at least 12 hours after simulator training.
    - High-risk activities include flying, climbing, driving, riding motorcycles, riding bicycles, or diving.
    - Use handrails to help maintain balance when going up or down stairs.

Future Research Suggested by this Literature Review

- *The effect of SS on training.* One of the key arguments offered for studying SS is the potential for compromised training. However, there is virtually no evidence to support this argument. There is no evidence showing a statistically significant difference in the amount learned as a function of reported level of discomfort.

- *The effect of chronological age on SS.* Does increasing adult age make one more susceptible to SS or less susceptible? Are older aviators more susceptible to SS because they are older, because they have more flight experience, or some combination of both? The two leading theories of SS make opposite predictions. The SC theory predicts that SS will decrease with increasing chronological age. The PI theory predicts that SS will increase with increasing chronological age.

Purpose of this Research

The purpose of this research was to measure SS both before and after exposure to a helicopter simulator that was being used for emergency procedures training. The research issues were the incidence and magnitude of SS, aftereffects, susceptibility, and the effect of SS on training. Of particular interest was the relationship between SS as reported on the SSQ and participant age, flight hrs, prior MS, prior SS, and performance on a test of training effectiveness.

This research was a small part of an experimental program of instruction in simulator-based emergency procedures training that was offered by the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) at Fort Rucker, AL. A description of this instructional program can be found in Couch and Johnson (2005). The Army aviator participants were required to take this training as part of their AH-64A Aircraft Qualification Course. ARI's data collection effort was permitted on a strictly non-interference basis. Hence, from ARI's perspective this was a "target of opportunity" to collect research data from an ongoing training activity. This research effort was not a controlled laboratory experiment, but rather a limited set of quasi-naturalistic observations.

Method

The Course of Instruction

All research participants were flight students who had graduated from Initial Entry Rotary Wing training, had received their wings, and were enrolled in an advanced course called an Aircraft Qualification Course (AQC). Many of these participants were transitioning from other aircraft after several years of Army aviation experience. This particular AQC was for the AH-64A Apache attack helicopter. All students enrolled in this AQC between 1 January 2001 and 21 January 2005 were required to participate in the ARI training. The course was called AH-64A Back Up Control System (BUCS) Familiarization Training (Couch & Johnson, 2005). This was simulator-based familiarization training concerning how to diagnose problems with the primary flight control system of the Apache, enable the fly-by-wire BUCS, and employ this back up system to fly and land the aircraft safely. It consisted of instruction in 44 tasks, in both the

pilot station and the copilot/gunner (CPG) station. The in-simulator portion of this training required 90 minutes.

The Simulator

The ARI Simulator Training Research Advanced Testbed for Aviation (STRATA) simulator was enlisted to provide the platform for this training, since no other simulator in the Army inventory, at the time, was capable of simulating the full range of BUCS flight procedures. Detailed descriptions of STRATA can be found in earlier reports (Johnson, 1997; Johnson & Stewart, 1999). Briefly, the STRATA training device was a fixed-base, full-mission simulator for the A-model Apache. The pilot and CPG cockpits were taken from aircraft number 83-23789. CAE Corporation designed, built, operated, and maintained this simulator at the ARI facility. STRATA, which incorporated a modular design capable of software modification, used a hydraulic digital control loading system to simulate all of the flight-control characteristics of the AH-64A—including BUCS.

A G-seat and active five-point shoulder harness provided acceleration, deceleration, and motion cues. All controls, instruments, and displays were functional and integrated with each other. Both cockpits were provided with three 100-inch, rear projection visual displays providing each station with a 180-degree horizontal by 45-degree vertical out-the-window FOV. For this training program what the aviators saw out their windscreens was a highly detailed, geo-specific terrain database rendered by three CAE Medallion™ image generators, which were capable of presenting 16,000 polygons per frame at a rate of 60 frames per second.

Participants

A total of 474 aviators participated in this research between 23 February 2001 and 7 November 2003. All participants were enrolled in the AH-64A AQC course and voluntarily agreed to participate in this research. All were native speakers of English. All were in their usual state of health and fitness, and none had been ill in the week prior to the simulator session. 463 (97.7%) of the participants were males. (Aviators taking the Apache advanced course have historically been overwhelmingly male.) The participants ranged in age from 20 to 58 years with a mean age of 30.4 ($SD = 7.1$). The range of total aircraft flight hrs for this sample varied from a low of 65 to a high of 17,000 with a mean of 1042.1 ($SD = 1901.3$). This sample contained 208 Commissioned Officers (43.9%), 263 Warrant Officers (55.5%), and 3 civilians (0.6%). Commissioned Officers ranged in rank from O1 to O5. Warrant Officers ranged from W1 to W4.

Data Collection Instruments

Simulator Sickness Questionnaire. As described above (Kennedy, Lane, et al, 1993), the SSQ consisted of a 16-item checklist of symptoms (e.g., fatigue, headache, eyestrain, etc.). For each of the symptoms, four levels of severity were listed (None, Slight, Moderate, Severe). The instructions printed on the questionnaire asked the respondent to "Please indicate the severity of symptoms that apply to you <u>right now</u> by circling the appropriate word."

Prior to simulator exposure (Pre Questionnaire). A one-page questionnaire was administered immediately prior to the simulator session. It included the SSQ symptom checklist as well as four additional yes or no questions:

1. Are you in your usual state of health and fitness?
2. Have you been ill in the past week?
3. Do you have a prior history of motion sickness?
4. Do you have a prior history of simulator sickness?

Immediately after simulator exposure (Post Questionnaire). The SSQ symptom checklist was administered immediately upon exiting the simulator. If, during the simulator session, there was an unscheduled break due to trainee discomfort, this "sickness event" was recorded by the author.

12 hrs after simulator exposure (Aftereffects Questionnaire). A one-page questionnaire was filled-out by each participant approximately 12 hrs after exiting the simulator. It included the SSQ symptom checklist as well as three yes or no questions:

1. Have you experienced any loss of muscular coordination or balance since leaving BUCS training?
2. Have you fallen down since leaving BUCS training?
3. Have you had an automobile or motorcycle accident since leaving BUCS training?

BUCS test. There were no formal tests of learning associated with this BUCS Familiarization Training that became a part of the student's AQC record. (This is one reason the course was titled "familiarization training.") ARI developed a BUCS performance test purely for pedagogical purposes. Neither the students nor their instructors were ever made aware of the results of these in-simulator tests.

Each student was given two no-notice test scenarios—once each in the pilot cockpit and the CPG cockpit. There were a total of four test scenarios. All test scenarios involved severances of some portion of the primary flight controls. All test scenarios occurred while either the pilot or the CPG had the controls and was operating (flying) the simulator.

Performance was scored by the BUCS subject matter expert (SME) based upon the information available to him at the instructor station. This information involved repeater screens that showed the simulator's out-the-window view, repeater screens that showed flight instruments, BUCS-specific information available on the instructor's screen, video cameras showing both cockpits, and the crew's audio intercom system. Performance on each test scenario was scored on a three-point scale: unsatisfactory (0), marginal (1), and satisfactory (2). Each student's total score, therefore, could range from a low of 0 (unsatisfactory on both test scenarios) to 4 (satisfactory on both test scenarios). To get a satisfactory score, the crewmember at the controls had to detect the problem, correctly diagnose it, communicate the situation to his or her fellow crewmember, execute the appropriate actions to enable the BUCS, get control of the aircraft, and return to a straight and level mode of flight. All scoring was performed by the same BUCS SME. This SME was naïve as to the results of all SSQ responses.

Procedure

Crews of research participants were scheduled to arrive at the ARI building at Fort Rucker for BUCS Familiarization Training in two-hr blocks. Each crew consisted of two aviators (pilot and CPG) who would switch cockpits mid-way through the 90-minute simulator session. Upon arrival trainees were ushered into a conference room, identified for purposes of the training record, and their demographic information was obtained, as well as their informed consent. Trainees who agreed to participate in the research, who were native speakers of English, and who met the health and fitness criteria, were then administered the Pre Questionnaire. To repeat, all trainees who arrived for training received BUCS training regardless of whether they participated in the research. However, the vast preponderance of AQC students who arrived for training met the research criteria and volunteered to participate.

Upon completion of the Pre Questionnaire, trainees were led into the simulator bay next door to begin their instruction. The ARI BUCS SME introduced each crewmember to his or her cockpit station, closed the curtains, lowered the ambient illumination, checked communication with the crew, and then began the instruction. Mid-way through this session, the crewmembers switched cockpits—which provided the only scheduled break. This break lasted 3-5 minutes.

The author was present at the instructor station during all simulator sessions to monitor participants for discomfort. The author recorded a "sickness event" whenever a participant required an unscheduled break in the instruction due to discomfort.

Upon the completion of instruction, trainees were returned to the conference room and immediately filled-out the Post Questionnaire. After the Post Questionnaire, but prior to leaving the building, all participants were given the Aftereffects Questionnaire and a self-addressed envelope. Participants were asked to fill-out the Aftereffects Questionnaire following a delay of approximately 12 hrs. They were also instructed how to return the questionnaire to the author, in the envelope provided, either in person or through local distribution channels.

Results

Scoring, Number of Observations, and Return Rate

The SSQ was scored as per Kennedy, Lane et al. (1993). The SSQ yields an index of Total Severity (SSQ-TS) as well as three subscale scores called Nausea, Oculomotor, and Disorientation. The SSQ-TS score was used for statistical analyses because it was the best index of overall SS. However, the three subscale score means were included for comprehensiveness of the archival record.

The BUCS test was scored as described above, providing each participant with a total score of 0 to 4. The author recorded a "1" for each participant who reported a history of motion sickness or a history of simulator sickness on the Pre Questionnaire. The author recorded a "1" for each participant who required an unscheduled break due to discomfort during a simulator session (sickness event). A "1" was also recorded for each participant who answered "yes" to any of the three aftereffects questions presented on the Aftereffects Questionnaire. The number

of observations (N) upon which each result is based is presented along with the specific statistic. Some of the yes/no questions were added after data collection had already begun, so the N for all statistics is not identical. (Again, these data were collected as observations from a training activity, rather than a formal experiment.) Of the total of 474 participants, 375 returned their Aftereffects Questionnaires for a return rate of 79.1 percent.

Incidence, SSQ Scores, and Sickness Events

Incidence of SS is usually defined as the percentage of total participants who report at least one symptom of discomfort. According to this method, the incidence rate prior to simulator exposure (Pre Questionnaire) was 47.9 percent (227/474). Immediately post simulator exposure (Post Questionnaire) the incidence rate was 68.1 percent (323/474). The incidence rate after 12 hrs (Aftereffects Questionnaire) was 35.7 percent (134/375).

The mean SSQ Total Severity scores reported before simulator exposure, immediately after simulator exposure, and 12 hrs later are presented in Table 3. Table 3 also presents the mean Difference Score, which is the mean of the individual Post scores minus the individual Pre scores. The difference of 8.14 between SSQ-TS Post and Pre was statistically significant (Wilcoxon Signed Ranks, $z = 11.03$, $p < .001$). The difference of 7.93 between SSQ-TS Post and 12 Hrs After was also statistically significant (Wilcoxon Signed Ranks, $z = 10.97$, $p < .001$). There was no statistically significant difference between SSQ-TS scores prior to simulator exposure and scores 12 hrs after exposure.

Table 3

Mean SSQ Total Severity Scores, *SD*, and *N* Measured Prior to Simulator Exposure, Immediately Post Simulator Exposure, and 12 Hrs After Simulator Exposure

Statistic	Prior (Pre Q)	Immediately Post (Post Q)	12 Hrs After (Aftereffects Q)	Difference Score (Post minus Pre)
M	4.59	12.73**	4.80	8.14
SD	7.39	16.89	10.45	16.02
N	474	474	375	474

** Post exposure score was significantly different from Pre ($p < .001$) and significantly different from 12 Hrs After ($p < .001$)

There were a total of 22 sickness events for a sickness event rate of 4.6 percent (22/474). That is, 22 participants experienced such a high level of discomfort while in the simulator that training was stopped for an unscheduled break. This rate does not mean that 22 participants vomited (emesis). It does mean, however, that their discomfort reached such a high level that a break was required for their safety.

Table 4 presents the mean SSQ subscale scores for the three measurement intervals (Pre, Post, 12 Hrs After). The three subscale scores (Nausea, Oculomotor, Disorientation) are presented to complete the archival record of these SSQ results. In every case the mean subscale scores at Post were higher than at Pre or 12 Hrs After.

Table 4

Mean SSQ Subscale Scores, *SD*, and *N* Measured Prior to Simulator Exposure, Immediately Post Simulator Exposure, and 12 Hrs After Simulator Exposure

Subscale	Prior (Pre Q)	Immediately Post (Post Q)	12 Hrs After (Aftereffects Q)
Nausea	$M = 3.56$ $SD = 7.27$ $N = 474$	$M = 10.63$ $SD = 17.80$ $N = 474$	$M = 3.36$ $SD = 9.14$ $N = 375$
Oculomotor	$M = 5.34$ $SD = 8.90$ $N = 474$	$M = 11.00$ $SD = 13.39$ $N = 474$	$M = 5.17$ $SD = 10.29$ $N = 375$
Disorientation	$M = 2.09$ $SD = 6.72$ $N = 474$	$M = 11.69$ $SD = 21.00$ $N = 474$	$M = 3.45$ $SD = 11.52$ $N = 375$

Other Aftereffects: Muscular Coordination, Falls, Automobile or Motorcycle Accidents

Of the 375 participants who returned the Aftereffects Questionnaire, all answered the three yes/no questions appended at the end. Twelve participants or 3.2 percent (12/375) reported that they had experienced a loss of muscular coordination or balance since leaving the simulator-based training. Only one participant (0.27%) reported having fallen down in the 12 hrs since leaving the training. No participant (0%) reported having had an automobile or motorcycle accident in the intervening 12 hrs since leaving the training.

Susceptibility Factors: Age, Flight Hrs, History of Motion Sickness and Simulator Sickness

Table 5 presents the bivariate correlations between SSQ scores and the susceptibility factors addressed in this research. Susceptibility factors are, by definition, those factors that predispose one to become sick during simulator exposure. In this research these factors were chronological age in years, total aircraft flight hrs, reported prior history of MS, and reported prior history of SS. These factors were correlated with two related measures of simulator sickness—SSQ-TS at the Post Questionnaire and the Difference Score (SSQ-TS Post minus SSQ-TS Pre). The author employed both the parametric Pearson (r) and the nonparametric Spearman (r_s) redundantly in order to assess the strength of the relationships independently of stringent statistical assumptions. Based on the literature reviewed above, all four susceptibility factors were expected to correlate positively with SSQ scores. That is, greater levels of each factor should be associated with greater levels of reported discomfort on the SSQ. Thus, all reported probability values (p) are one-tailed. A negative correlation coefficient for any of these factors would be rejected as not statistically significant (*ns*).

Three methodological points emerged from Table 5. First, the results were the same whether these data were correlated using the parametric r statistic or the nonparametric r_s. Second, the results were the same whether one used the Post score alone or the Difference Score. For these data, the two measures were highly and positively correlated ($r = 0.90, p < .001$). Third, age and flight hrs were strongly and positively correlated ($r = 0.71, p < .001$).

Table 5 shows the correlations between history of motion-related discomfort and SSQ scores from this simulator exposure. Reported prior history of MS was significantly and positively correlated with both SSQ measures ($r = 0.19, p < .01$; $r = 0.14, p < .05$). Reported prior history of SS was also significantly and positively correlated with both measures ($r = 0.24, p < .001$; $r = 0.29, p < .001$). The correlation coefficients for history of SS and SSQ scores were larger than those for history of MS and SSQ scores.

Table 5

Parametric Pearson Correlations (r) and Nonparametric Spearman Correlations (r_s) Between SSQ Scores and Susceptibility Factors

Factors	N	Pearson r	Spearman r_s
SSQ-TS (Post) x Difference Score	474	$0.90, p < .001$	$0.77, p < .001$
Prior MS x SSQ-TS (Post)	180	$0.19, p < .01$	$0.14, p < .05$
Prior MS x Difference Score	180	$0.14, p < .05$	$0.13, p < .05$
Prior SS x SSQ-TS (Post)	180	$0.24, p < .001$	$0.25, p < .001$
Prior SS x Difference Score	180	$0.29, p < .001$	$0.25, p < .001$
Flight Hrs x SSQ-TS (Post)	438	$0.12, p < .01$	$0.14, p < .01$
Flight Hrs x Difference Score	438	$0.12, p < .01$	$0.12, p < .01$
Age x SSQ-TS (Post)	474	$0.22, p < .001$	$0.19, p < .001$
Age x Difference Score	474	$0.20, p < .001$	$0.15, p < .001$
Age x Flight Hrs	438	$0.71, p < .001$	$0.74, p < .001$

Also shown in Table 5, age was significantly and positively correlated with SSQ score whether measured by Post score ($r = 0.22, p < .001$) or Difference Score ($r = 0.20, p < .001$). Flight hrs were also significantly and positively correlated with SSQ score ($r = 0.12, p < .01$) no matter how measured. That is, older aviators and aviators with a greater number of flight hrs

were more likely to report increased SS. However, given the strong positive correlation between age and flight hrs reported above, these significant bivariate correlations were confounded with each other. The statistical technique of partial correlation allows one to untangle this confounding and estimate the true relationship between each factor and SSQ scores with the other factor held constant mathematically. Table 6 presents the partial correlation (*pr*) of age on SSQ scores, with the effect of flight hrs held constant. This table also presents the partial correlation of flight hrs on SSQ scores, with the effect of age held constant.

Table 6

Partial Correlation (*pr*) of Age and Flight Hrs on SSQ Scores

Factors		*N*	Partial Correlation (*pr*)
Age x SSQ-TS (Post)	[Flt Hrs controlled]	438	0.16, $p < .001$
Age x Difference Score	[Flt Hrs controlled]	438	0.14, $p < .01$
Flt Hrs x SSQ-TS (Post)	[Age controlled]	438	-0.03, *ns*
Flt Hrs x Difference Score	[Age controlled]	438	-0.01, *ns*

As shown in Table 6, the relationship between age and both SSQ measures, with the confounding effect of flight hrs held constant, was statistically significant ($pr = 0.16, p < .001$; $pr = 0.14, p < .01$). The same was not true for flight hrs. Once the confounding effect of age was removed, there was no relationship between flight hrs and either SSQ measure. These results suggest that the susceptibility factor that was operating here was age of aviator and not flight hrs.

It must be acknowledged that all of the correlations between susceptibility factors and SSQ scores, though statistically significant, were relatively weak. The strongest of the four factors measured in this research was reported prior history of SS.

SSQ Scores and Amount Learned

As described in the literature review above, simulator-induced discomfort has for decades been expected to correlate inversely with measures of amount learned or training effectiveness. That is, the sicker the participant, the less that participant is expected to learn from the simulator-based training. Hence, the author expected a negative correlation coefficient between SSQ scores and performance on the BUCS test. Thus a one-tailed test was used. Table 7 presents the results of the bivariate correlations between both measures of SS and total score on the BUCS test. Again, the author employed the parametric Pearson r and the nonparametric Spearman r_s redundantly.

Table 7

Parametric Pearson Correlations (r) and Nonparametric Spearman Correlations (r_s) Between SSQ Scores and Performance on the BUCS Test

Measures Correlated	*N*	Pearson r	Spearman r_s
BUCS test score x SSQ-TS (Post)	215	-0.01, *ns*	-0.01, *ns*
BUCS test score x Difference Score	215	0.01, *ns*	0.01, *ns*

Once again the results obtained were not affected by the correlation technique employed. Aviator performance on the BUCS test did not correlate with scores on the SSQ. That is, amount learned as measured by performance sampled by the BUCS test was not related to amount of discomfort reported on the SSQ. This result was contrary to the stated expectations of the author, as described above. However, the psychometric properties of the BUCS test were less than optimal, as demonstrated in Table 8.

Table 8

Descriptive Statistics of Results* from BUCS Test

M	*Mdn*	Mode	*SD*	Range of Scores	Percent of Total *N* Receiving Highest Score
3.62	4	4	0.63	1 to 4	69.8 (150/215)

* $N = 215$

Table 8 presents the descriptive statistics for the results obtained from the BUCS test. As described in the Method section above, the total score possible for any participant was four. Approximately 70 percent of the participants who were administered the BUCS test received this highest score. The median and mode were also four with a mean of 3.62. Clearly, there was a ceiling effect operating to reduce variability. Thus, whatever the truth of the research hypothesis, the BUCS test was insufficiently sensitive to measure the critical dependent variable.

Discussion

Incidence, SSQ Scores, and Sickness Events

Incidence. Immediately after simulator exposure, the incidence rate reported in this research was 68.1 percent. This result was consistent with past research which showed that, depending upon conditions and simulators, incidence of SS ranged from 0 to 90 percent (Kennedy, et al., 1987; Kennedy & Fowlkes, 1992; Kennedy & Frank, 1985; McCauley, 1984; Pausch et al., 1992). Specific to helicopter simulators, Wright (1995) reported that by using the

current lax criterion incidence rose to 70 percent. Kennedy and colleagues (Kennedy et al., 1988; Kennedy et al., 1989) reported incidence rates for helicopter simulators as high as 69 percent. Gower et al. (1987) reported an incidence rate of 44 percent for the CMS simulator which represents the AH-64A helicopter. Thus, the incidence rates reported in this research are consistent with the results reported earlier.

SSQ scores. The mean SSQ-TS scores from this research were 4.59 (negligible symptoms) prior to simulator exposure, 12.73 (significant symptoms) immediately post exposure, and 4.80 (negligible symptoms) after 12 hrs. SSQ results from prior studies are presented in Table 1 above. Table 1 shows that Durbin and colleagues (Durbin et al., 2003; Durbin & Hicks, in preparation) and Stoffregen et al. (2000) reported mean scores ranging from 4 to 6 prior to simulator exposure. Also reported in Table 1 were mean post exposure scores. For simulators representing RW aircraft, SSQ-TS scores ranged from 7 to 20. The largest study (Kennedy et al., 2003) reported the results of 3,000 observations of participants operating eight military helicopter simulators. In this study the overall post exposure score was 12.63. Thus, the results of the present research were consistent with prior research using RW simulators.

The results from the incidence measures as well as the SSQ measures showed that participants arrived for simulator-based training reporting greater than zero symptoms, that these reported symptoms increased substantially as a result of simulator exposure, and then these reported symptoms returned to prior exposure levels after a period of approximately 12 hrs had elapsed. Results such as these are by now well established in the simulator research and simulator-based training communities. For this reason, guidelines have been published (c.f., Crowley & Gower, 1988; Johnson, 2005; Kennedy et al., 1987; Lilienthal et al., 1987; NTSC, 1988; Wright, 1995). All these guidelines recommended that participants avoid high-risk activities for several hrs after exiting the training simulator.

Sickness events. In the present research 22 participants, or 4.6 percent, experienced such a high level of discomfort that training had to be stopped temporarily. These results were consistent with experience in the training community, where an informal rule-of- thumb has emerged that approximately 10 percent of the participants will experience pronounced discomfort possibly leading to aftereffects (Kennedy et al., 1988; Kennedy & Fowlkes, 1992).

Other Aftereffects: Muscular Coordination, Falls, Automobile or Motorcycle Accidents

The potential for dangerous aftereffects of simulator exposure has been noted from the dawn of visual helicopter simulator-based training (Miller & Goodson, 1958; 1960). These potentially dangerous aftereffects have included ataxia, loss of balance, disorientation, and automobile or aircraft safety. Virtually every research report mentions this dangerous potential, although it is the rare report that provides any data relevant to the issue. Baltzley et al. (1989) reported results from a large study involving 742 simulator exposures across 11 Navy and Army simulators. Of the pilots who reported symptoms of SS, the most common category of aftereffect was nausea (51%), followed by disorientation (28%). Crowley (1987) reported that 11 percent of his sample of helicopter pilots experienced aftereffects of simulator training. The most commonly reported delayed symptom was a perception of illusory movement.

In the present research, 12 participants (3.2%) reported that they had experienced a loss of muscular coordination or balance since leaving the simulator-based training. One participant (0.27%) reported falling down and no participant (0%) reported having been involved in an automobile or motorcycle accident since leaving the simulator. These results were consistent with previous authors who reported that there were no documented cases of flight incidents or automobile accidents linked to prior simulator-based training (Crowley, 1987; Kennedy & Frank, 1985; McCauley, 1984; Wright, 1995). Thus, the results of the current research support the established conclusion that while the *potential* exists for simulator-linked safety issues, so far in *practice* no such linkage has been documented.

Susceptibility Factors: Age, Flight Hrs, History of Motion Sickness and Simulator Sickness

In this research, chronological age of pilots and flight experience measured in hrs were strongly and positively correlated. Older aviators were significantly more likely to have more flight experience than were younger aviators. This was a finding that has been reported before by Magee et al. (1988) and discussed by Tsang (2003). Interestingly, the Pearson correlation coefficient reported by Magee et al. was 0.67, while in the present research the Pearson coefficient was 0.71. Clearly this finding was consistent with earlier research.

A second methodological point concerns the dependent variable when analyzing the SSQ. The developers of the SSQ (Kennedy, Lane, et al., 1993) recommended using the post exposure score alone—in this case the SSQ-TS post. Other researchers (cf., Regan & Ramsey, 1996) have chosen to use the difference between the post score and the pre score—in this case the Difference Score. In the present research the correlation between the two measures was strong, positive, and statistically significant. Hence, the results reported in Table 5 showed no practical difference in findings regardless of which of the two measures was employed.

Age and flight hrs. Aviator age was positively and significantly correlated with both measures of SS after the confounding effects of aviator experience were removed by partial correlation. Aviator experience as measured by flight hrs, however, was not correlated with SS after the effects of age were removed by partial correlation. For these data, the factor that was responsible for making older, high-time aviators susceptible to SS was their age, not their flight experience. However, although statistically significant, this effect of age was not large—with *pr* equal to 0.16 and 0.14.

The author was unable to find much support for this age effect in the simulation literature. As discussed above, this may be because researchers have historically aggregated their data by flight hrs rather than by aviator age. Warner et al. (1993) found that his older group was much more likely than his younger group to terminate the flight simulator session prematurely due to severe SS. Based upon research using an automobile-driving simulator, Hein (1993) reported that older drivers were highly susceptible to SS, in contrast to younger drivers. Magee et al. (1988) reported that a partial correlation of flight hrs against measured SS, with age held constant, resulted in a small (0.03) and statistically insignificant relationship. This last finding (Magee et al.) was directly comparable to the results for flight hrs as reported above in Table 6.

These results support the PI theory (e.g., Riccio & Stoffregen, 1991). As described above in the literature review, the PI theory predicts that SS will increase with increasing postural instability. Increasing adult age is indisputably associated with increased postural instability. Thus, the PI theory predicts that measured SS will increase with increasing adult age. The SC theory (e.g., Reason & Brand, 1975) makes the opposite prediction. This theory predicts a reduction in measured SS with increasing age because increasing age provides increased opportunities to experience—and adapt to—novel motion environments. In the special world of aviation, where age and flight experience are highly correlated, proponents of SC theory have historically claimed that a primary variable influencing susceptibility to SS was aircraft flight hrs (e.g., Braithwaite & Braithwaite, 1990; Crowley, 1987; Gower & Fowlkes, 1989b; McGuinness et al., 1981; Miller & Goodson, 1958; 1960). The current research, in agreement with that of Magee et al. (1988), found that with age held constant flight hrs were not related to SS.

Prior history of motion sickness. The present research found that reported prior history of MS was positively and significantly correlated with both SSQ measures. Aviators who reported a prior history of MS were also more likely to report elevated levels of SS during simulator exposure in the present research. This result agreed with earlier research that has found a near universal relationship between history of MS and reported discomfort levels during simulator training (Braithwaite & Braithwaite, 1990; Gower & Fowlkes, 1989a; 1989b; Gower et al., 1989; Gower et al., 1987; Kennedy et al., 1988; Lampton et al., 1995; Lerman et al., 1993). There is nothing surprising about this consistent pattern of results. SS is a form of MS. Participants who experience increased susceptibility to MS symptoms can logically be expected to experience increased susceptibility to SS symptoms.

Prior history of simulator sickness. The susceptibility factor that correlated most strongly with SSQ scores in this research was prior history of SS. Participants who reported a history of SS were more likely to experience increased levels of discomfort upon simulator exposure in the present research. This result is a special case of the general rule that prior history of MS is predictive of SS upon exposure to a flight simulator. That is, aviators who have experienced SS in previous simulators, are more likely to experience SS in future simulators. Past behavior is the best predictor of future behavior.

SSQ Scores and Amount Learned

The present research found no relationship between measures of SS and amount learned as assessed by the BUCS test. However, this result is admittedly suspect for several reasons. First, the BUCS test was brief, covering only a small subset of the program of instruction. Second, the BUCS test was insufficiently sensitive, since a ceiling effect appeared to truncate variability. Third, there was no measure of inter-rater-reliability because there was only one SME to perform the scoring of the BUCS test. Given these psychometric weaknesses one cannot argue that the hypothesized inverse relationship between SS and training effectiveness has been given a fair opportunity to emerge. So the question of whether simulator-induced discomfort significantly reduces training effectiveness remains unanswered. Given the practical importance of this question, further empirical research is warranted.

As discussed in the literature review above, the author could find no prior research that directly and objectively tested this hypothesis. The prior research by Chappelow (1988) and by Gower and colleagues (Gower & Fowlkes, 1989a; 1989b; Gower et al., 1989) provided indirect evidence in the form of aviator opinion surveys. These surveys consistently reported that the preponderance of aviators believed that simulator-induced discomfort did not hamper simulator-based training.

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